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THE USE OF SUSTAINABILITY INDICATORS IN INDUSTRIAL APPLICATIONS

Master's Thesis for the degree of Master of Science in Technology submitted for inspection, Espoo, 20th November, 2013.

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Abstract of master's thesis

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Abstract

Sustainability as a concept consists of three categories: environmental, economic and social sustainability. The concept of sustainability is relatively wide and the collected data needs to be significantly compressed in order to interpret it and make truthful conclusions. Data compressing can be done with the help of sustainability indicators.

Indicators are a powerful tool for compressing large amounts of data into few indices and hence getting comprehensible results of complex issues. The total sustainability of an industrial plant can be measured and evaluated with sustainability indicators created especially for this purpose. Indicators are an illustrative way of evaluating operational areas that are organized well and operational areas that need to be improved.

In this thesis the Metric project sustainability index is tested through two case examples in order to see if the index is a usable tool for industrial applications assessment. The used case examples are before-known in order to simplify the evaluation of the indicator tool. Recommendations for improving the sustainability indicator tool are made based on the given results from the case examples.

The goal of this thesis is to canvass if the Metric project sustainability indicator tool is convenient for industrial needs and what still needs to be improved. The tool is created especially for internal use for a company for estimating the sustainability of an industrial plant. The tool can be used e.g. when a company is building a plant, purchasing a plant or planning to make an industrial investment.

Keywords Sustainability, sustainable development, indicators, index tool, steel industry

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Tiivistelmä

Kestävyys (sustainability) voidaan määritellä kolmen eri osa-alueen avulla, jotka ovat ympäristönäkökulma, taloudellinen näkökulma ja sosiaalinen näkökulma. Kestävyys on käsitteenä melko laaja ja sen takia kerättyä pohja-aineistoa tulee tiivistää, jotta se olisi helposti tulkittavissa. Pohja-aineiston tiivistäminen voidaan tehdä esimerkiksi kestävyysindikaattorien avulla.

Indikaattorien avulla pystytään tiivistämään huomattava määrä tietoa muutamaksi, helposti tulkittavaksi indeksiksi. Indikaattorit ovat käyttökelpoisia apuvälineitä erityisesti monimutkaisten asioiden ja asiayhteyksien tulkitsemiseen. Indikaattorien avulla voidaan helposti löytää ne toiminnan osa-alueet, jotka ovat hyvin kehittyneitä ja toimivia, sekä ne osa-alueet, joita voidaan edelleen parantaa.

Tässä työssä testataan Metric-projektissa luodun kestävyysindeksityökalun toimintaa kahden case-esimerkin avulla. Case-esimerkit ovat ennalta tuttuja, jotta indeksin arvioiminen työkaluna olisi mahdollisimman yksiselitteistä. Case-esimerkkien avulla pyritään arvioimaan indeksityökalun toimivuutta ja löytämään kehitysehdotukset sen eteenpäin viemiselle.

Työn tarkoituksena on arvioida, onko kestävyysindeksityökalu käyttökelpoinen teollisuuden tarpeisiin ja mitä parannettavaa siinä vielä on. Työkalu on suunnattu erityisesti teollisuusyrityksille sisäiseen käyttöön kestävyyden mittaamisen apuvälineeksi tehdastasolla. Työkalua voidaan hyödyntää esimerkiksi tilanteissa, joissa rakennetaan tai ostetaan teollisuuslaitos tai suunnitellaan uutta investointia jo olemassa olevaan laitokseen.

Avainsanat Kestävyys, kestävä kehitys, indikaattorit, indeksityökalu, terästeollisuus

Foreword

This Master's Thesis is written to Metric project in Aalto University, Laboratory of Mechanical Process Technology and Recycling, in 2013. I am thankful for the possibility to write my Master's Thesis about this interesting subject.

I would especially like to thank my supervisor Professor Kari Heiskanen and my instructor Professor Olli Dahl for many good advices and help with the project material during the thesis work. I would like to thank Nani Pajunen and other members of the Metric project for great help with the project material.

Also I would like to thank my family and friends for support during my studies and encouragement during my Master's Thesis work.

Espoo, 20.11.2013

Kirsi Virtanen

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Abbreviations

AMD	Acid mine drainage
AQI	Air Quality Index
BAT	Best Available Techniques
BOD	Biochemical Oxygen Demand
BREF	BAT Reference Documents
CDM	Clean Development Mechanism
COD	Chemical Oxygen Demand
CR	Current Ratio
CS	Corporate Sustainability
CSR	Corporate Social Responsibility
EIO	Environmental Input-Output
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GRI	Global Reporting Initiative
IED	Industrial Emissions Directive
IPPC	Integrated Pollution Prevention and Control
JI	Joint Implementation
LCP	Large Combustion Plants
NGO	Non-Governmental Organization
PA	Process Analysis
PPP GDP	Purchasing Power Parity corrected Gross Domestic Product
QR	Quick Ratio
ROA	Return on Assets
ROCE	Return on Capital Employed

ROE	Return on Equity
ROI	Return on Investment
RONA	Return on Net Assets
VOC	Volatile Organic Compounds
WF	Water Footprint
WGI	Worldwide Governance Indicators
WSI	Water Stress Indicator

1 Introduction

Sustainability is a widely known and used concept for describing the system's ability to endure and recover. Sustainability as a concept is closely connected to ecology. It can be used to estimate different processes that have an effect on the environment. Sustainability can be defined as a non-declining welfare in the long run. [1]

Sustainability can be measured with indicators. These indicators are created in three different approaches, which are environmental, social and economic approach. Before the indicators are created, the industry stakeholders and their interests must be recognized. [1]

Composite indicators are a good way of simplifying a large set of data into a handful on descriptive numbers. They are able to describe complex issues quite accurately. Composite indicators are seen useful especially in describing environmental issues. The indicators can be either simple or weighed. The type of the indicator depends on the importance of the factor. There can also be inter-correlations between the indicators. This means that a factor can be taken into account more than once. [1]

In the Aalto University Metric-project one of the main project goals is to combine the above mentioned three different sustainability viewpoints and to create a powerful tool for estimating and analysing sustainability in industrial applications. A properly working sustainability tool can help decision making in the factory level and also in the governmental level. This tool can be useful estimation tool for a company when planning, building or purchasing a plant. [1]

In this thesis the main idea is to test the sustainability index tool previously created in the Metric-project. The testing is done with two known case examples, cases 1 and 2. In both of these cases there is some kind of an adjustment or investment done in the process and the idea is to measure the sustainability indices before and after the adjustment. With the given case data the process sustainability state and its alteration is measured. The usability and utility of the indicators is evaluated. The indicators are to be developed further in case their approach towards sustainability seems to be e.g. too theoretical. [1]

2 Sustainability indices

2.1 General

Sustainability is an important and wide concept for describing how well e.g. a country or a factory is operating. Industrial companies have become more aware about sustainability issues in recent years. Sustainability has three different approaches, which are environmental, social and economic. Composite indicators are an effective and innovative way of describing and evaluating sustainability matters. [1, 2]

A functional way to improve industrial sustainability is to create sustainability indices to be used as a tool for sustainability estimation. First step in creating the indices is to identify industry stakeholders and understand their interests. When these are known the construction of the sustainability indicators can be started. [2]

Sustainability can be outlined to be the development that meets the needs of the present without compromising the ability of future generations to meet their own needs [3]. Sustainability describes the ability of a system to recover from e.g. industrial actions. Measuring of the sustainability performance of an industry sector is important for keeping the 'social licence' for continuing operations. [2]

The three main aspects of sustainability can be illustrated with three separate circles describing unsustainable development or with three overlapping circles describing sustainable development. These circles are shown below in figures 1 and 2. [4]

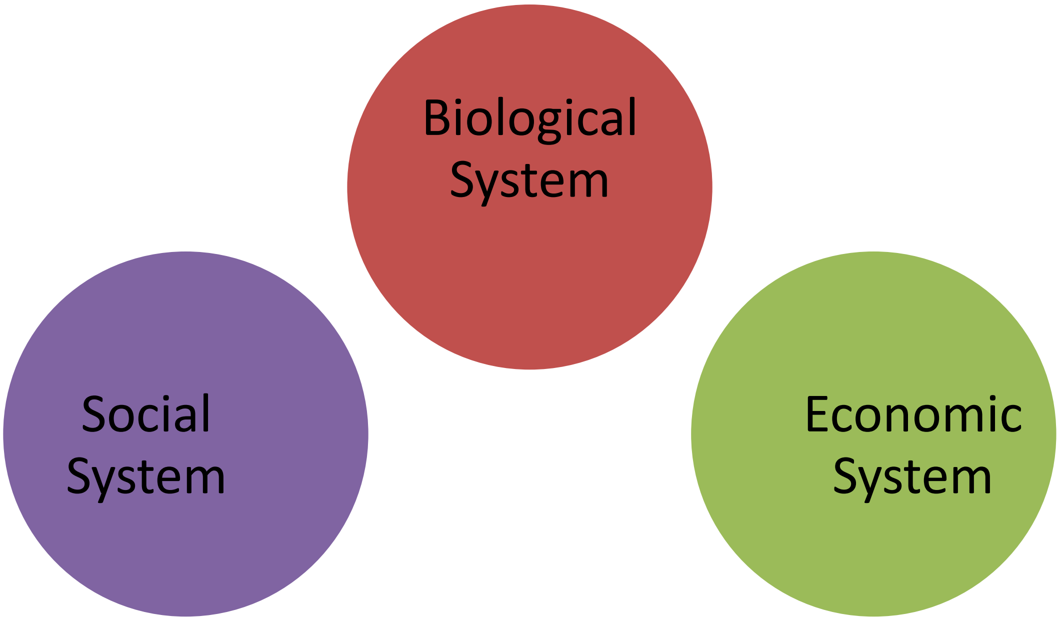

Figure 1. Unsustainable development [original picture from reference 4].

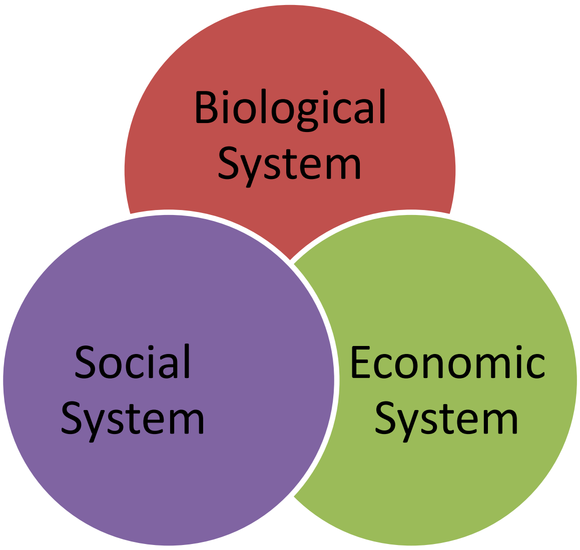

Figure 2. Sustainable Development [original picture from reference 4].

In case all the three aspects of sustainability (environmental, social and economic systems) are not taken into account when observing a situation, the observation is one-sided and the given results are unreliable [5]. Operating in a sustainable way can improve also the economic situation of a plant. By improving the health and safety issues, the labour costs can be lowered. Cleaner methods and more efficient production can reduce the raw material costs and plant closure costs. Investors and consumers are also starting to be more interested in highly reputable companies. [2]

For example the mining and minerals industrial sector provides vital raw materials for many other industries and creates wealth and employment to the society. Minerals production is a significant part of the Gross Domestic Product (GDP) in many countries. Despite the positive social and economic effects, there are also a lot of sustainable development challenges for mining and minerals industry. Minerals are mostly non-renewable resources, which makes the operations inevitably unsustainable on the environmental point of view. Landscape disturbance and health and safety risks are also sustainability challenges for this industry sector. [2]

2.2 Industry stakeholders

The industry stakeholders must be identified and their interests recognized for creating meaningful and functional sustainability indicators for the industry. Industry stakeholders are e.g. employees, trade unions, customers, suppliers, contractors, insurers, shareholders, creditors, local communities and non-governmental organizations (NGOs), local authorities and governments. It should also be evaluated how important a specific stakeholder is to a certain industry sector. [2]

Industry provides a direct employment for a great many people in the world. This makes employment probably the most important industry stakeholder. Trade unions are interested in labour issues, such as health and safety, equality and fair treatment to mention a few. In the worst case, a trade union can create a division between the workers and the management, which reduces sustainability. At its best, trade union creates work commitment and participation which is the core of sustainability. [2]

In the mining and minerals industry the contractors make the most of the operations, for example drilling, loading, hauling, permitting and closures. Economic performance of the main company and future prospects for further contracts are the biggest interests for the contractors. Suppliers are very similar to contractors: they provide different chemicals, materials, energy and services to the main company. Their main interest is similar to the contractor's main interest. [2]

Generally speaking, customers act according to the economics theory: they want to buy the needed products with minimum price with no risks. This highlights the profitability of the company as an important interest. Shareholders have traditionally been interested on shareholder returns, but there is also a new trend about socially responsible investing. This means that shareholders have started to avoid unacceptably operating companies and invest more in socially and environmentally responsible companies. Creditors are commercial banks providing financial support for industry. Ethical and sustainability issues are becoming more important also for creditors. [2]

Insurers' interests are diversified. They are interested in all sustainability areas: environmental, social and economic. In mining and minerals field they are especially concerned for the mine closure liabilities, because in several countries the 'polluter pays' principle is in use. [2]

Local authorities are a special stakeholder group because they are closely involved to a plant during its whole life cycle starting from planning and ending at decommissioning. Local authorities also are interested in all aspects of sustainability, for instance employment, state of the environment and social issues. They have also an important role in implementing laws and regulations and dividing the profit of the industry equally in the local society. [2]

Government's interests are close to the local authorities' interests. The contribution to GDP is also important. They create the frameworks for operations, e.g. environmental standards, planning process regulations, revenue and taxes. [2]

Non-governmental organizations, the NGOs, are non-profit-making organizations that operate independently from the government. They are usually funded by the public or private sector. As a stakeholder NGOs are the most interested in environmental and social issues. They can co-operate with the industry and campaign for certain issues to make them familiar with the public. [2, 6]

2.3 Indicators and indices

After the identification of industry stakeholders and their interests, it is important to recognize the key concerns of sustainability issues. They should be easily quantifiable measures of the performance. The stakeholder analysis should help in highlighting main issues. They should be observed by the help of the 'cradle to grave' principle, which means that the whole supply chain is taken into account. [2]

Indices are very useful in describing a large amount of data and complex issues in a simple and understandable way. Indices condense information of a large data set into a small group of numerical values, which make the information very easy to interpret. [7]

A good example of a successful economic index is the Gross Domestic Product, GDP. It is globally known and used for political decision making. Different countries and their progress can be compared with each other by using GDP. There are also some deficiencies in GDP: for example it does not take into account the economic inequality in a society, which has a strong effect on the society and welfare. GDP is discussed in more detail later in this thesis. [7, 8]

Another example of a successful index is the Greenhouse Gas Index published in the 1990. It summed up greenhouse gas emissions yearly for each major country. This index was easy to interpret and became widely known and gathered public attention. The Greenhouse Gas Index became at first very controversial but also provoked conversation, research and policy actions globally. [7]

In index construction the primary data and final index values are separate from each other. Primary data is first analyzed and then used in constructing the indicators. Indices are created based on the indicators. The basic idea of the construction of an index from primary data is shown in figure 3 below. [7]

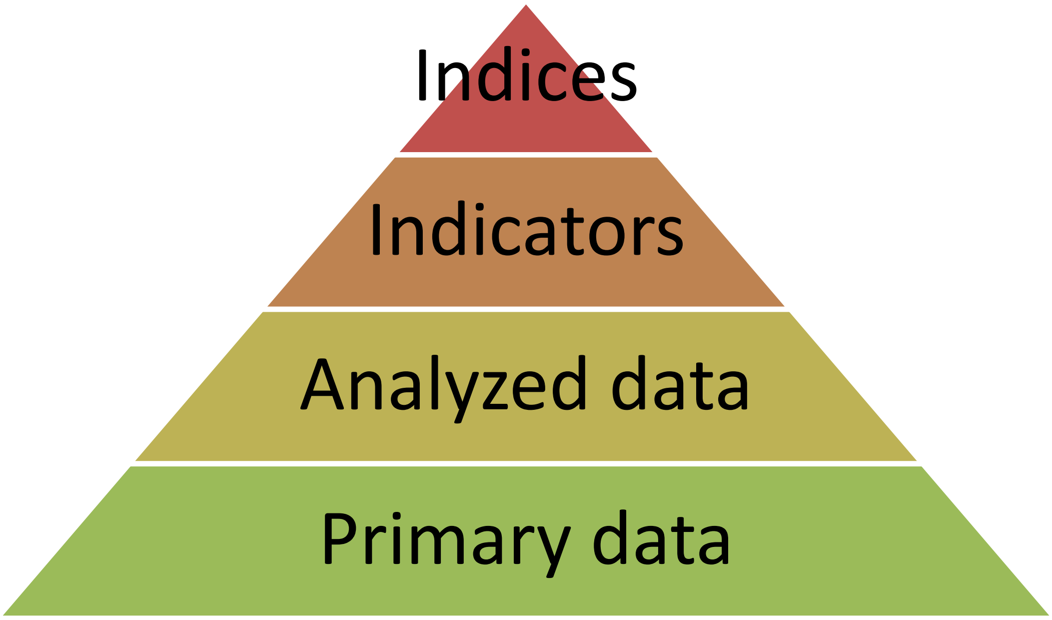

Figure 3. The Information Pyramid [original picture from reference 7].

Indices can be a great help in decision making. They describe the state and changes of different issues. The alteration of an issue and trends can be seen when evaluating and comparing the index data. Indicators are constructed by measuring quantitative or qualitative data. The basic data must be scientifically proven to be true for achieving reliable results and conclusions. In most cases there are many different aspects to a single matter. A composite indicator is a functional way of describing different aspects simultaneously. [1, 5]

2.4 Composite indicators

The main purpose of composite indicators is to simplify complex issues. This enables a multi-aspect evaluation of a specific problem. Composite indicators can be used as a help in decision making when all aspects must be taken into account. [1, 5]

Composite indicators can be either simple of weighted. Simple indicator gives equal weight for all components. As for weighted indicators, higher weighted indicator component is considered to be more important than a lower weighted indicator component. Weighted composite indicators can be used e.g. when one of the indicator components has been shown to have a greater impact on the environment than the others. [1]

There can also be inter-correlations between the indicators and hence, some aspects might already be double-weighted in the indicators. Correlation analysis estimates the correlations between indicators. Highly correlated indicators can be weighted lower to make the results more reliable. [1]

There is also some criticism towards composite indicators. In a composite indicator the indicator components are assumed to be each other's substitutes. In reality this is not always true. It is also possible that one indicator component masks the other and the results are not useful for making right conclusions. The quality of the used data when constructing the indicators is essential. If the data is incorrect the results most likely are controversial. [1]

There are several already existing sustainability indices, for instance Dow Jones Sustainability Index (DJSI) published by RobecoSAM and S&P Dow Jones Indices. It is a global index family that benchmarks the world's largest companies and their performance in social, environmental and economic areas. DJSI only includes companies that fulfill certain criteria of sustainability issues. It is one of the first published and continuously monitored sustainability indices in the world. The DJSI is a practical tool for companies when their sustainability needs to be evaluated and improved and for investors to help them with the investment decision. DJSI more or less emphasizes the meaning of leadership, management and strategy. [9, 10]

Global 100 is a relatively simple sustainability index by S&P Dow Jones Indices. It measures the performance of 100 multi-national companies. It has evenly weighed components. In figure 4 below can be seen the Global 100 index performance value as a function of time for five years' time period starting from 4th August 2008 and ending at 30th July 2013. [10, 11]

Figure 4. Global 100 index performance from 4th August 2008 to 30th July 2013. [11]

2.5 Environmental sustainability index

2.5.1 General

The most important environmental sustainability issues are e.g., use of energy, water, land and other resources, emissions and discharge, solid and toxic waste, loss in biodiversity and disturbance. These issues mostly have negative effects on the environment. This is why it is important to estimate that the nature is in some extent capable of recovering from these impacts. The capability to recover depends on the characteristic of a specific industry. For instance in mining and minerals industry a significant portion of the mined minerals are non-renewable. [2]

There are some well-known environmental indices for sustainability evaluation. These are e.g. carbon footprint and water footprint. They are discussed in more detail below. [10]

Environmental indicators can be dealt into three different groups: pressure, state and response indicators. Environmental pressure indicators measure the stress caused by human activities towards a certain environmental area. Pressure indicators are e.g. emission measurements, amounts of waste, forest depletion or some other changes in the environment. Environmental pressure indicators are relatively easy to measure and usually their data availability is good. By pressure indicators it can be seen if the pressure towards the environment has increased or decreased. [7]

State indicators measure the biological or physical state of the environment. They are e.g. air quality in cities, ozone layer thickness or fish stocks. Response indicators measure the efforts taken by the society to reduce or prevent an environmental problem. These efforts are e.g. research, budget commitments, agreements and voluntary changes, regulatory compliance and incentives. [7]

2.5.2 Industrial emissions and waste

In a basic industrial process there is certain input and output of energy and materials. The basic idea in the process description is that the material and energy fed into the process eventually come out in some form. These are called the material and energy balances of a process. The basic industrial process description is shown in figure 5 below. [10, 12]

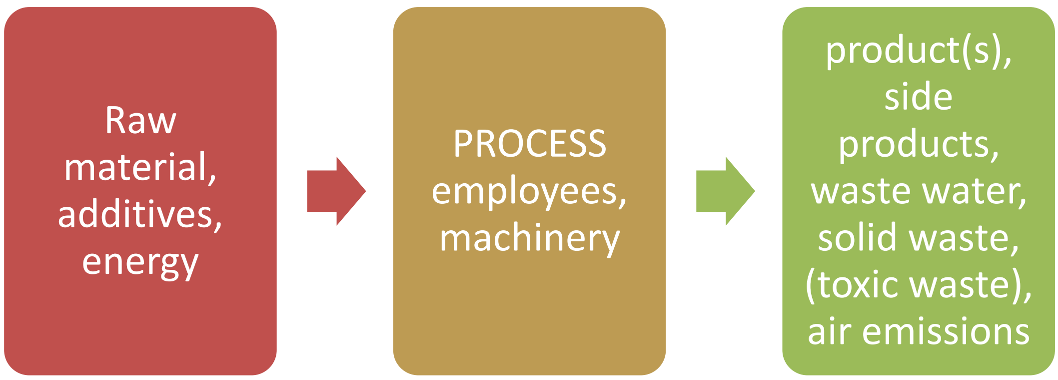

Figure 5. Basic description of an industrial process. [12]

Process input in most cases consists of raw material, additives and energy. The output is the main product and possible side products, waste water, solid waste and emissions. All these process factors are bound to each other so that if one factor changes the others also vary. [10]

Outside of this process description there is the raw material production emissions, electricity production emissions, main product and side product life cycles, recycling and waste treatment. These above mentioned factors are also remarkable when evaluating sustainability of a process. In more complex process cases with multiplicity of variables it can be challenging to recognize and evaluate the whole production chain. Hence when the sustainability of a production chain is estimated the balance limits must be drawn as wide as possible, but in such a way that estimation is still possible with adequate accuracy. [10]

The limiting factors of a process can vary regionally caused by e.g. legislation or natural resources. For instance in northern Europe fresh water is not an issue but in Australian mines water consumption must be considered more carefully. [10]

Industrial activities create a considerable amount of emissions and waste in global scale. When compared to household emissions, the amount of industry emissions is over twice as much. Agriculture, forestry, energy supply and transport greenhouse gas emissions are also significant. Energy supply and transport are closely connected to industrial activities. Global greenhouse gas emissions divided by their source in 2004 are shown in figure 6 below. [13]

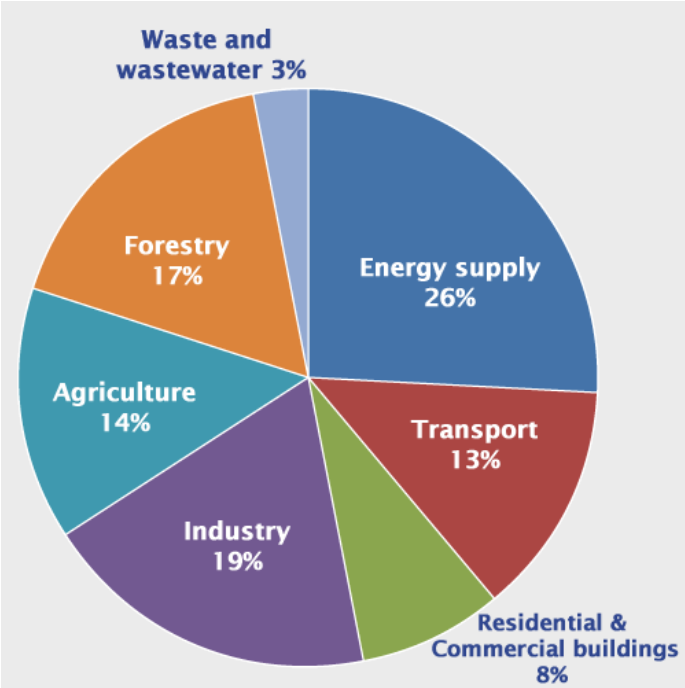

Figure 6. Global greenhouse gas emissions in 2004 divided by source. [13]

Most industrial activities cause emissions and discharge and produce solid waste. Usually when one of the waste or emission streams reduces, the others increase because of the material and energy balances of the process. This often occurs in connection with environmental investments, in which the goal usually is to reduce one striking emission or waste stream. Increase in electricity consumption or raw material consumption has a negative effect on the total sustainability of an operation. With properly built sustainability indicators it is possible to estimate if the planned investment truly improves the total sustainability of an operation. [10]

2.5.3 Solid waste

There are four definitions for different types of solid waste. These are Municipal Solid Waste (MSW), hazardous waste, other waste and sewage sludge. MSW consists of household, trade and commercial wastes collected by the municipality. For instance schools, hospitals, small businesses and offices produce MSW. Hazardous waste is dangerous or difficult to treat and dispose. It can be e.g. toxic, reactive, infectious or irritant, corrosive or carcinogenic. [14]

Other waste consists of industrial, agricultural and commercial wastes. These are e.g. demolition and construction waste, mining and metallurgical waste, industrial ashes and end-of-life vehicles. Sewage sludge consists of household, industrial and commercial effluent. The content of sewage sludge depends largely on its origin. [14]

The formation of different waste types (million tonnes per year) in Finland in 2009 is shown in the figure 16 below. It can be seen in the figure that the portion of mineral waste is significant when compared to other waste type amounts. The amount of wood waste in the figure 16 is calculated excluding waste utilized in agriculture and logging waste left on site. The amount of sewage sludge in the figure 7 is calculated as dry weight. [14]

Figure 7. Waste formation in Finland in 2009 divided by different waste types. [14]

Waste can be treated by separating it into different segments. These are Solid Recovered Fuel (SRF), Refuse Derived Fuel (RDF) and MSW. The waste type terminology is shown in figure 8 below. SRF is prepared from non-hazardous waste and can be used as a fuel in waste incineration plants. RDF is shredded or pressure treated MSW, which consists mostly of plastics and biodegradable waste. The use of waste as a waste incineration fuel reduces the amount of waste in landfill. Waste incineration creates relatively small amounts of energy that can be e.g. used in district heating. In some cases even sewage sludge can be used as a waste incineration fuel in fluidized bed reactor. [14]

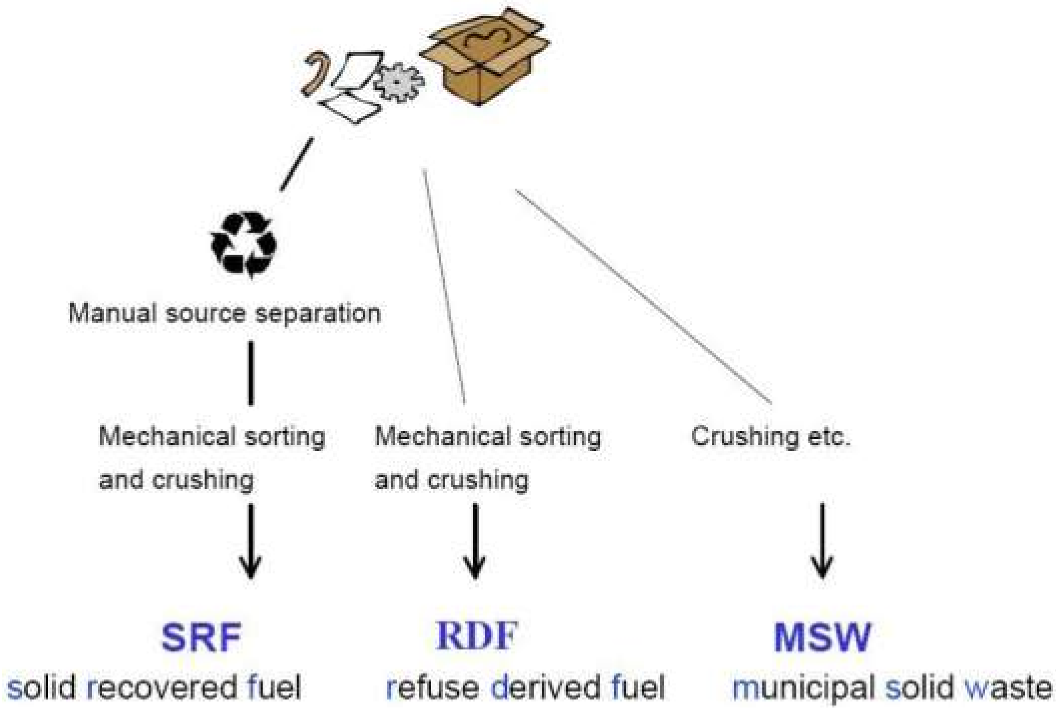

Figure 8. Terminology of waste separation. [14]

Recycling can be dealt into four different categories, which are primary recycling, secondary recycling, tertiary recycling and quaternary recycling. Primary recycling in industrial level refers to material recycling of uncontaminated waste. A good example of primary industrial recycling is the collection and use of small steel particles as a raw material in a steel factory. Secondary recycling uses post-consumer products as a raw material for new products. [14]

Tertiary recycling is the production of a value-added product by e.g. treating recycled material in a chemical process. This type of recycling is useful for instance for reuse of monomers, solvents of fuels. Quaternary recycling stands for the use of a product as a fuel in energy production. [14]

Industrial waste can in some cases be taken to use as a raw material for another process or as a fuel in energy production. This procedure often turns the industrial waste into a side product. Some industrial side products, for example agricultural side products such as straw, can be used as a fuel in combustion. Another good example of this 'industrial recycling' is the use of treated steel factory blast furnace slag. [14, 15]

In a blast furnace the formation of slag is 150-250 kg per one tonne of iron. It is cooled rapidly with water and it forms vitreous slag granules less than 5 mm in size. Most of the slag granules can be used further, e.g. as a substitute of stone aggregate material in road construction, alloying element in cement, binding element in concrete, in soil work as soil improvement or filling material. The slag can also be treated in a barrel in order to make porous and light weight slag pellet. Slag pellets are used as a body material in concrete industry, as an insulator or as an alloying element in cement manufacturing. [15]

Minimizing the amount of waste created in a process and the amount of material put into a landfill is advisable. Waste in a landfill causes larger total environmental load than the incinerated waste. Leaching substances and landfill gas are the biggest environmental problems concerning landfills. Leaching substances are liquids that migrate from the landfill to the surrounding soil and groundwater. Landfill gas is a mixture of gases formed in the landfill waste. The basic formation of landfill gas in three stages is shown in figure 9 below. The composition of landfill gas as a function of time is shown in figure 10 below. [14]

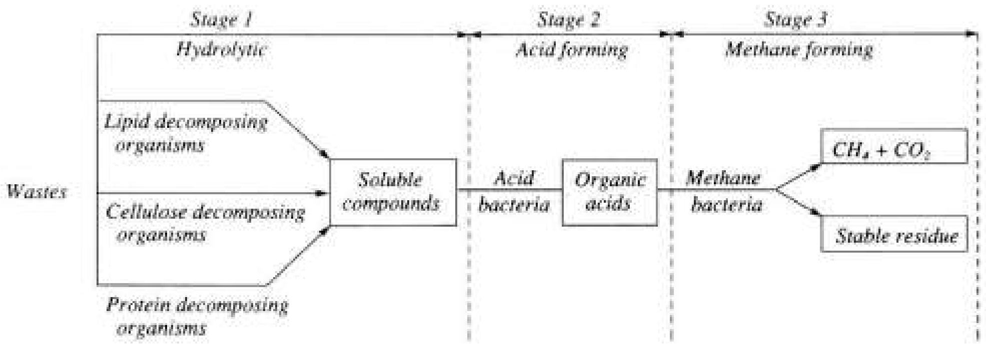

Figure 9. The formation of landfill gas. [14]

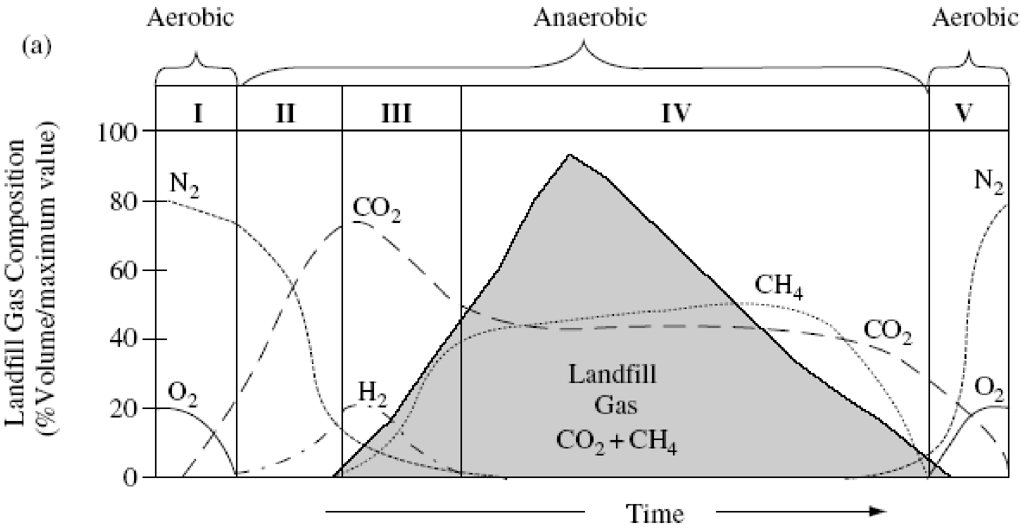

Figure 10. The composition of landfill gas as a function of time. [14]

2.5.4 Emissions

The industry causes e.g. CO_2, SO_2 and NO_x emissions. These gases must be filtered out from the plant flue gases sufficiently because they form sulphuric and nitric acid in the atmosphere and cause acidification in the environment. The pollutants can be filtered out from flue gases with e.g. cyclone, electrostatic precipitator or with wet scrubber, dry scrubber and semi-dry scrubber. Desulphurization is performed to remove acidic compounds from the flue gases. A forest damaged by acid rain is shown in the figure 11 below. [14, 16]

Figure 11. Acid rain effects on a forest. [16]

In industrial emissions, there are small particles which are harmful for human health. Especially particles smaller than 2.5 μm in diameter are a health risk. These fine particles increase the risk of lung cancer and other lung related diseases. This risk is the biggest for long-term stay in metropolitan area. The 2.5 μm particles are measured by a $PM_{2.5}$ value. There is also a PM_{10} value for particles smaller than 10 μm in diameter. These are considered to be coarse particles. Maximum amounts of particle concentrations in air are for fine particles (2.5 μm) 25 $\mu g/m^3$ with averaging period of 1 year and for coarse particles (10 μm) 50 $\mu g/m^3$ with averaging period of 24 hours and 40 $\mu g/m^3$ with averaging period of 1 year. [17, 18]

Employees' exposure for harmful and hazardous substances can be measured with HTP value. HTP is a Finnish abbreviation and stands for 'Haitallisiksi tunnetut pitoisuudet', in English, Concentrations Known to be Hazardous. There are HTP_{8h} and HTP_{15min} values for different exposure durations, the other one for eight hours working day and the other one for only 15 minutes exposure. The HTP value is defined separately for different industrial chemicals. The HTP value for small particles is expressed as mass concentration [mg/m³] in air. For gases and vapors the HTP unit is volume concentration [ppm] and as mass concentration. The HTP_{8h} value upper limit for inorganic dust is 10 mg/m³. [19]

Air Quality Index (AQI) measures the air quality based on five indicators: small particles of $PM_{2.5}$ and PM_{10}, ground-level ozone, carbon monoxide and sulphur and nitrogen dioxide. AQI gives a value between 0 – 500 to describe the air quality at the moment. The results are also colour-coded to visualize the results. The AQI results and their meanings are listed in figure 12 below. [20]

Air Quality Index Levels of Health Concern	Numerical Value	Meaning
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk
Moderate	51 to 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health warnings of emergency conditions. The entire population is more likely to be affected.
Hazardous	301 to 500	Health alert: everyone may experience more serious health effects

Figure 12. Different levels of AQI and their meanings. [20]

In Helsinki the air quality situation measured with the AQI is on average good or moderate. E.g. in Beijing there is at times significant overrun of the amount of particles compared to the health recommendation limits. The air quality measurement results in Beijing in January 2013 have even exceeded the AQI numerical value upper limit of 500 for hazardous air quality. [21, 22, 23]

The following figures 13 and 14 show satellite pictures of Beijing City taken by NASA on different days. In the figure 13 can be seen a severe smog cloud over the area in 14.1.2013. In figure 14 there is the situation 11 days earlier in 3.1.2013. In these pictures it can be seen that the air quality situation varies greatly. The highest measures of AQI are usually taken in Beijing in the wintertime. [22]

Figure 13. NASA earth observatory satellite picture of Beijing city in 14.1.2013. [original picture 22]

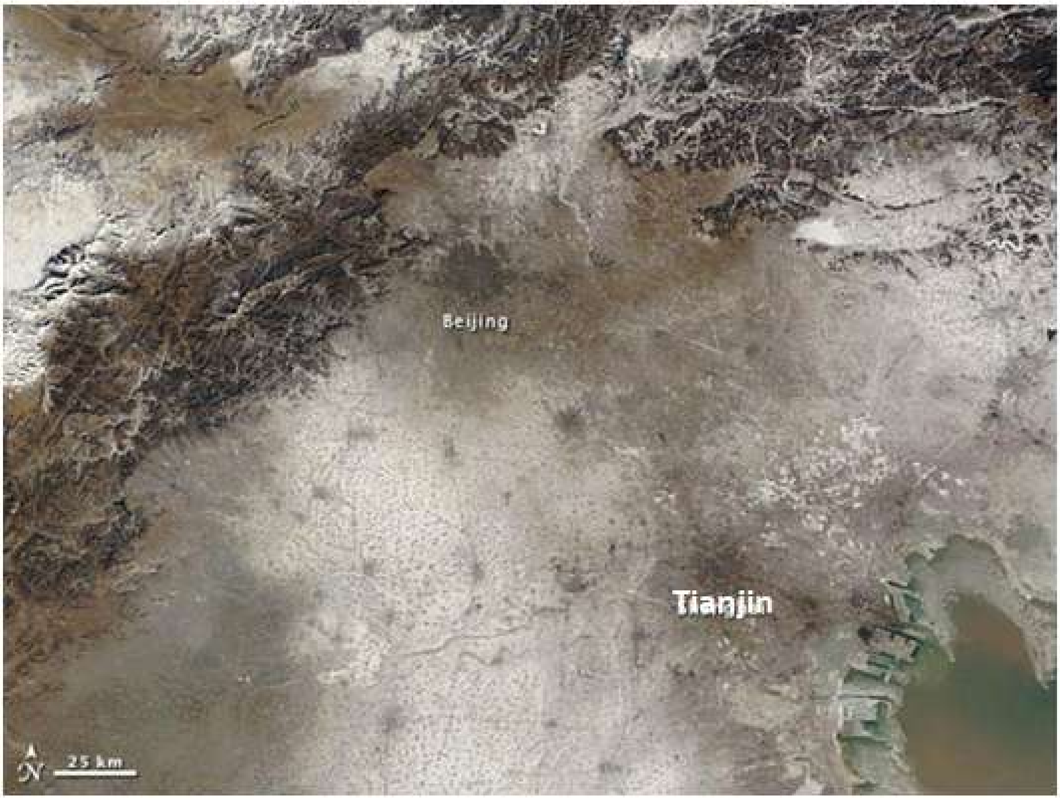

Figure 14. NASA earth observatory satellite picture of Beijing city in 3.1.2013. [original picture 22]

In global scale CO_2 emissions are often measured as CO_2 emission per country or territory or CO_2 emissions per capita for each country. A world map resized according to the relative amounts of CO_2 emissions of different areas in 2009 is shown in figure 15 below. The meaning of the colours on the map is to clarify the borders of different areas. A world map describing the CO_2 emissions per capita in 2006 is shown in figure 16 below. Darker coloured areas show larger CO_2 emissions per capita and lighter coloured areas show smaller CO_2 emissions per capita. [24, 25]

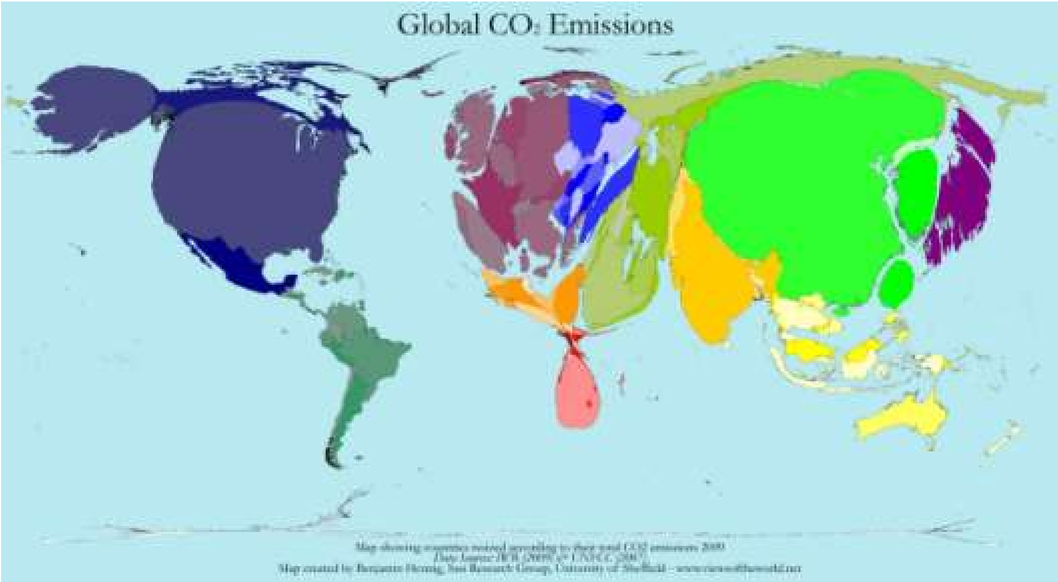

Figure 15. Resized world map showing the CO_2 emissions in 2009. [24]

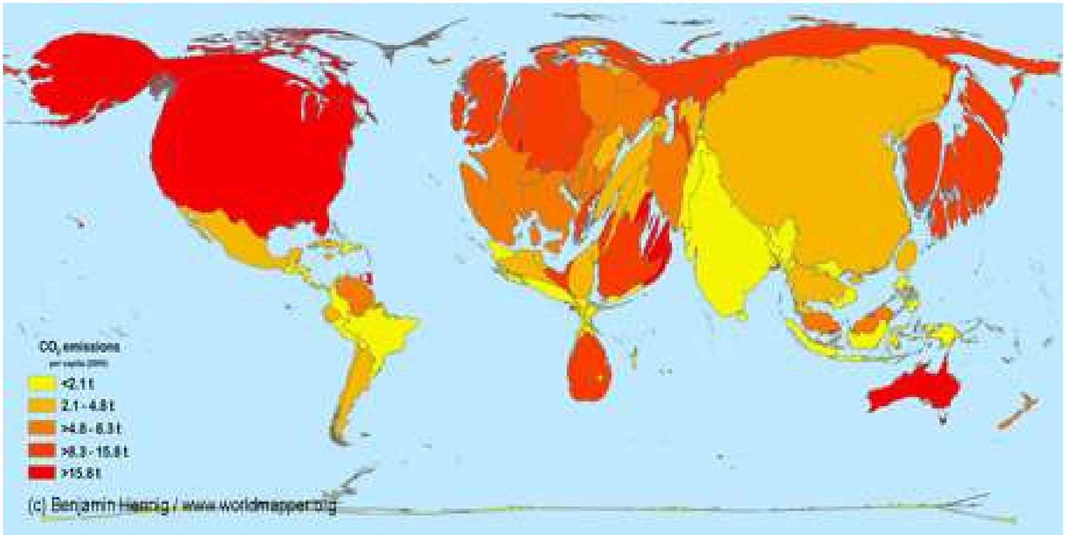

Figure 16. World map of CO_2 emissions per capita in 2006. [25]

A good example of a greenhouse gas emission indicator is the Carbon Footprint. It is a widely known concept in the public and media and it has been made into a product. Carbon footprint often means the total amount of greenhouse gases produced by some function or industrial activity. However, calculation methods for carbon footprint are weakly available and they differ from each other. There seems to be no consensus of how to calculate the carbon footprint unambiguously. [26, 27]

In some carbon equivalent calculation methods there are only CO_2 emissions taken into account, which makes the carbon footprint a synonym for carbon dioxide emissions. In some cases also other Greenhouse Gases (GHG) are taken into account by calculating an environmental carbon equivalent. In some calculation methods only direct carbon emissions are taken into account while others observe the whole life cycle of a product. This enables a large alteration in the results depending on the chosen calculation method. Measurements are usually recorded in kilograms or tonnes. [26]

In a sustainability point of view the carbon footprint analysis should be as extensive as possible in order to get truthful and convincing results. An extensive analysis takes the whole life cycle of a product or service into account: material manufacture, product manufacture, use, disposal and transportation in every part of the life cycle. The carbon footprint analysis can be done in three ways: Environmental Input-Output-analysis (EIO), Process Analysis (PA) or a hybrid of these two. [26]

A close relative to carbon footprint is ecological footprint, which is usually measured in hectares [ha], or 'global hectares' [gha]. Global hectare describes the global average productivity capacity of a land area. Bio-productivity on the planet differs a little from year to year, so the global hectare value can also vary. [26, 28]

2.5.5 Discharge

The availability of fresh water differs greatly in different parts of the globe. In northern countries water is not a limiting factor, but in dry areas lack of water can cause massive problems. Water scarcity can be described with many different indices created for this purpose. The calculations are usually based on the amount of available water resources and human population rate. [29]

The Falkenmark Indicator is probably the most popular water stress indicator. It defines the water stress in scale no stress, stress, scarcity, and absolute scarcity. Basic Human Water Requirements defines water scarcity by the ability to meet basic human needs. These are drinking water (5 liters/day/person), sanitation (20 liters/day/person), bathing (15 liters/day/person) and food preparation (10 liters/day/person). The total amount of water for all of these needs is 50 liters/day/person. [29]

The figure 17 below shows the global Water Stress Indicator (WSI). The light color describes areas where water scarcity is not an issue. Darker colors show the over exploited areas with larger water stress. [30]

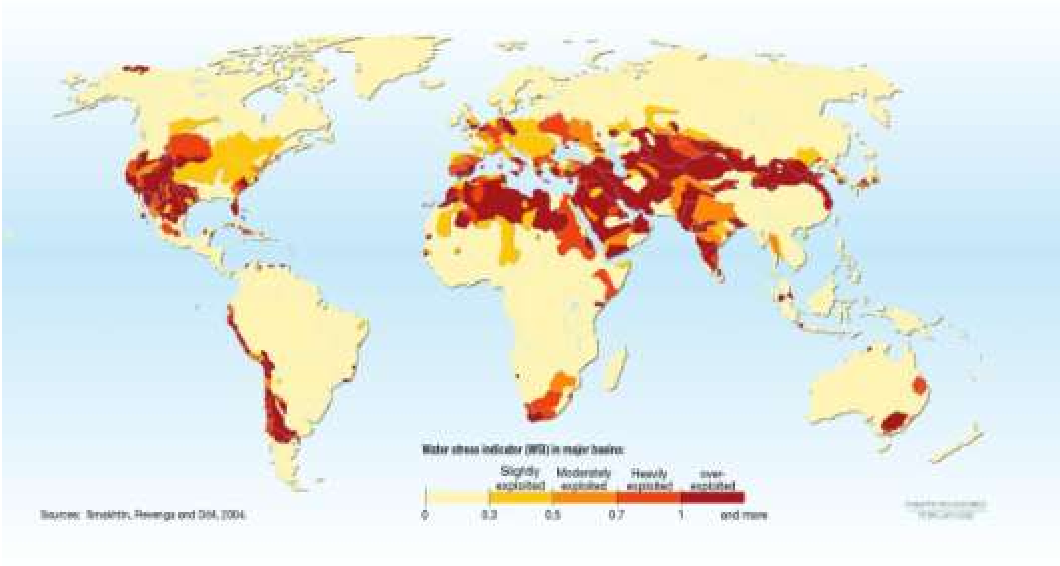

Figure 17. Global water scarcity rate. [30]

Industrial waste water is the main cause of aquatic pollution. Industrial waste waters often contain heavy metals, which must be removed before bleeding the waste water out of the industrial system. Metal removal from waste water can be done e.g. by ion exchange, membrane filtration, adsorption or precipitation. [31]

Because of the water scarcity in some areas of the globe, it is questionable to practice water-intensive industry in dry areas. In case this is done, the water treatment and preventing pollution must be done carefully. Approximately 70 % of the fresh water in the world is used for agricultural operations. In some areas of the globe there is continuous water scarcity. Because of the large amount of water required for agriculture, water scarcity forces people to buy food elsewhere. Cereal crops import correlates with water scarcity rate of the area. Hence cereal crops import rate can be used as a water scarcity indicator. [10, 29]

Industrial water handling should be relatively inexpensive. Natural materials that are commonly available are a good raw material for industrial water cleaning. The material used should not need any further treatment after heavy metal removal in order to keep the costs low. If possible, the use of another industrial waste or side product is advisable. For instance coconut tree fibers (coir pith) have been tested successfully for removing heavy metals from industrial waste waters. Increase in the amount of carbon in the process increased the heavy metals removal efficiency. [31]

For instance mine water pollution to surface water streams is globally a significant factor. Mine water pollution often causes lower pH value and higher amounts of solute metals in surface waters. This phenomenon is called the acid mine drainage. [32]

Acid mine drainage is an environmental risk in abandoned or disused mine sites. Acid mine drainage (AMD) occurs when sulphides (the most common is pyrite) and oxygen are present in the mine pit filled with water. The pH value reduces and metals start to dissolve into the water. A prerequisite for this phenomenon is that there are not enough alkaline materials present to neutralize the solution fast enough. When this water leaches from the mine pit, dissolved metals spread into the surrounding areas and aquatic ecosystems. AMD can happen either biotically by bacterial oxidation or abiotically without the bacteria. [32]

Closed or abandoned mines are not continuously pumped to remove water from the mine pit. AMD can be prevented e.g. by controlling the amount of oxygen in the sulphide mine pit. The mine can also be covered with different soil materials, for instance with clay or gravel and plant vegetation on area to prevent soil erosion. [32]

Water footprint (WF) is a relatively new sustainability indicator describing the fresh water use of a household, community or an industry. It was published in 2002 to improve the environmental sustainability evaluation tools. Water footprint is considered to be more descriptive sustainability indicator than carbon footprint, because the fresh water resources on earth are limited. Fresh water resources are also disunited on earth so that in some places water is not an issue and in other places there is a constant lack of water. Water shortage reduces the countries' self-sufficiency. [33, 34]

In water footprint calculations, waters are dealt into three categories: green water, blue water and gray water. Green water is the same as rainwater. Blue water means fresh ground water or surface water from lakes or rivers. Gray water is polluted water. These three water types are distinguished and weighed differently in the water footprint calculation. Water footprint is measured in unit m^3/year. [34]

The major part of water footprint for average consumer consists of food production. Cereal crops production is the heaviest, followed by meat and milk products. Coffee production has also a relatively big water footprint. The average consumer's water footprint in western countries is substantially higher than in developing countries in Africa of Asia. The average water footprint in the time period 1996-2005 (m^3 per year per capita) is shown in figure 18 below. [34, 35]

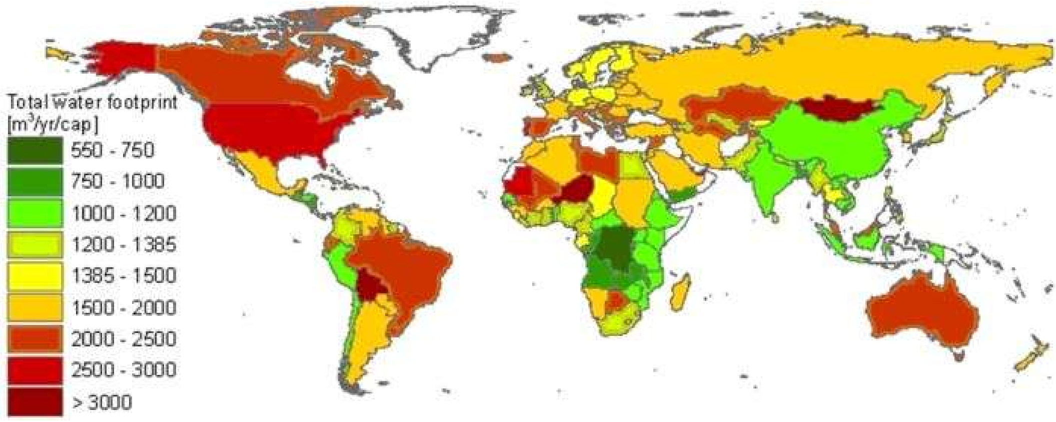

Figure 18. The global total Water Footprint (m^3 per year per capita) in the time period 1996-2005. [35]

2.5.6 Non-renewable resources and resource depletion

Fossil fuels (crude oil, coal, natural gas) are a good example of very slowly renewable natural resources. The regeneration is so slow that they can be considered to be non-renewable resources and they cannot be sustained infinitely. [7, 36]

For instance in mining and minerals sector the raw material in most cases is non-renewable. Nevertheless these minerals are very important for the society as a raw material for many purposes. Leaving them out would affect strongly on the current state of well-being of humankind. [3, 7]

Depletion of the ozone layer is caused by pollution in the stratosphere that catalyses the ozone decomposition reaction. Depletion can occur also in renewable resources as e.g. reduced amounts of fish stocks or forest areas. In this case the fishing or harvesting rate is too large and the recovery does not have enough time to occur properly. Groundwater circulation, sufficient water resources and soil degradation are also a concern in some areas. [7]

The index of resource depletion is an estimation of how much does the operations departure from sustainable resources use. It contains an assumption that if the created assets are equal value when compared to the resources, the depletion is sustainable. This index can be measured separately e.g. for each country. The resource depreciation can be compared to e.g. gross fixed capital formation or to sector domestic product. [7]

In addition to the previously mentioned environmental impacts, noise and vibration affect the plant surroundings and disturb the biodiversity nearby. For instance mining and minerals industry causes noise and vibration because of drilling, blasting and hauling works. Visual impacts are strong especially in mining and minerals industry site areas. [10]

One way to measure the environmental load of a product is the Ecological Rucksack. The Ecological Rucksack measures the needed natural resources during the whole life cycle of a product. The unit is in kilograms or tonnes. This way e.g. different products and raw materials and their environmental loads can be compared to each other. [37]

2.5.7 Industrial discharge treatment

Industrial processes use water as diluents for raw material and additives, for washing and rinsing, for achieving the needed process chemistry (e.g. in paper mills) and to produce steam. The industry also creates significant amounts of different types of waste waters. [38]

The industrial waste water is cleaned by using many different methods, which are divided into four categories: mechanical, chemical, biological and special methods. There can also be combinations of these before mentioned method types. Mechanical methods include e.g. clarification, flotation and filtration. Precipitation and flocking are considered as chemical methods. Biological methods are divided into aerobic and anaerobic methods. Special methods include e.g. activated carbon adsorption, vaporization, chemical oxidation, ion exchange separation, refrigeration distillation and magnetic separation. Forest industry waste water impurities and their sizes are shown in figure 19 below. [38]

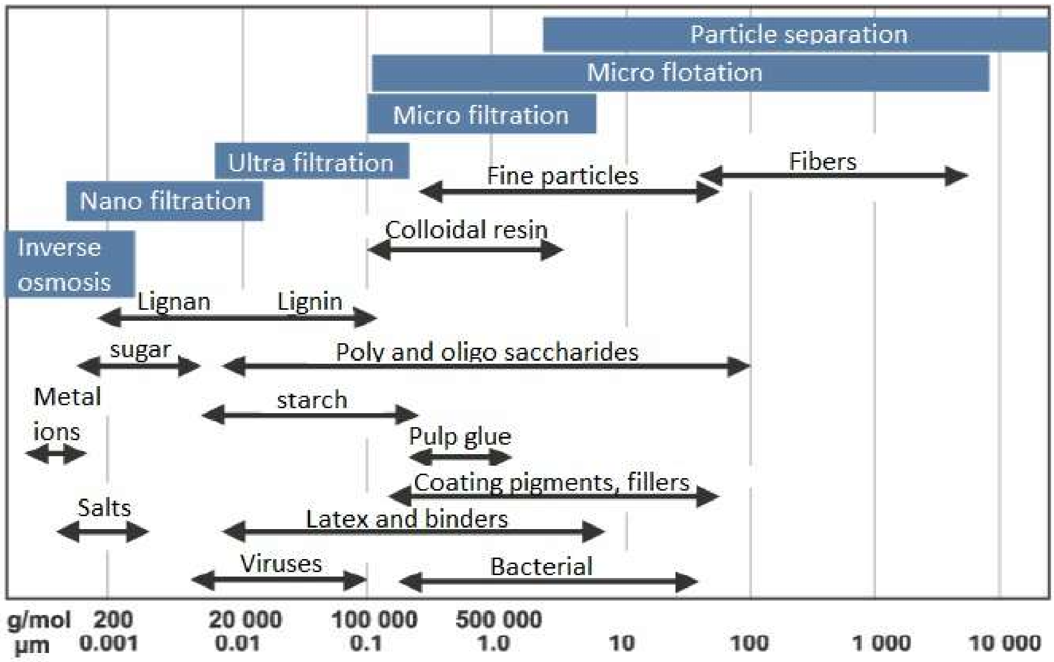

Figure 19. Forest industry waste water impurities and their sizes. [original picture: reference 38, free translation]

In case the water is left without treatment, there are several phenomena that have an effect on the surrounding environment. These effects are e.g. reducing the amount of oxygen in the water caused by organic load, eutrophication and opacity of the water. The amount of silt increases in the waterway bottom and hence makes the waterway shallower. Increase in Biochemical Oxygen Demand (BOD) and

Chemical Oxygen Demand (COD) decrease the amount of oxygen in the water system, which reduces the living comfort of fish species and also increases the internal load of the water system in case the bottom gets into oxygen-poor state. Eutrophication in water systems is mainly caused by phosphorus which is for instance in lakes a minimum amount nutrient. Due to eutrophication, the amount of coarse fish species increases and the recreational use value decreases. [38]

The most effective way to reduce the industrial water consumption is to circulate the process water inside the factory and process phases. The circulated water should be cleaned only to a sufficient level for the process purposes, completely cleaned water that can be bled into the waterways is often not necessary inside the process. [38]

2.5.8 Best Available Techniques and Reference Documents

Best Available Technique (BAT) is a European Union standard published in directive 2008/1/EC. BATs are created with a view to reduce the environmental impacts and emissions of industry and also agriculture. BATs define the most effective technical methods and represent relatively new technology. Best Available Techniques for different industrial areas are listed in Best Available Techniques Reference Documents (BREF). [39, 40]

There are several BREF documents published for different industrial fields. The work on some BREF documents is started but they are not published yet. There are documents for e.g. different metals production, woodworking industry, energy efficiency and cooling systems, waste water and waste gas treatment, different areas of food production, chemical industry and waste incineration. BATs and BREF documents should be followed especially when an industrial investment or an entire factory is built in order to minimize the impacts on the environment. [39, 40]

2.6 Economic sustainability index

2.6.1 General

The economic performance of an industry is an important factor when creating wealth and employment to a society. An industrial company must be profitable enough to be able to survive in the markets. A straightforward way to improve the economic performance of a company is to minimize costs and maximize profits and shareholder returns. This must be done inside the given environmental and social legislation boundaries. This is called the micro-level performance. Successful performance in micro-economic level can lead to benefits also in macro-economic level and for instance increase the Gross Domestic Product (GDP) and well-being of the surrounding society. [2]

The most important economic sustainability issues of an industry are costs, sales and profits, wealth creation and effect on the GDP, value added as a result of the production and the financial, social and environmental investments. Competitiveness, productivity and profitability are vital factors for an industrial company in order to succeed in the markets. [2, 12]

2.6.2 Investments and process development

Industrial investment usually is a land or equipment purchase made by an industrial company. The purpose of an investment is to start, improve or accelerate industrial production in order to make the industrial operations more profitable. The basic meaning of an investment is to create more income in the future. An investment that does not create any financial profit is in economic point of view considered to be an expense. Increasing process efficiency and process optimization usually also reduces raw material and energy needs. This reduces the operation costs of a plant and hence increases profit. [10]

An industrial investment can be economically evaluated with the Present Value method. In this method the future cash flow and costs of an investment are discounted to be equivalent to their financial value today. Discounting value of an investment is calculated according to the equation 1.

$$PV_T = \frac{x_T}{(1+r)^T}. \quad (1)\ [12]$$

In the above formula PV is the present value, x is the cash flow or cost, T is time and r is the discounting interest rate. Practically this method suggests that the value of money decreases as a function of time. Especially when the investment repayment period is relatively long, the present value of the future income decreases as it can be seen in the above formula. [12]

The economic performance of an investment can be measured with economic indicators, for instance with Return on Investment (ROI) indicator. ROI is a relatively simple and hence popular economic metric. It is calculated according to the equation 2.

$$ROI = \frac{Gain\ from\ investment - Cost\ of\ investment}{Cost\ of\ investment}. \quad (2)\ [12]$$

Environmental investments are often made because of a change in environmental legislation. However, an environmental investment can in some cases improve the profitability of a process in case the raw material or energy requirement decreases. Environmental investment can also improve the responsible business reputation of a company. This can have a positive effect on the company profitability by persuading more customers. Consumers in general are increasingly conscious of environmental issues. Environmentally and socially responsible operations have become an interest in addition to the product price. One measurement for the necessity of an environmental investment is the amount of human lives it probably saves in the future. [10, 12]

A new investment should be planned and evaluated carefully before the final decision is made. Especially the sustainability of an environmental investment should be evaluated thoroughly. This is important in order to see if the investment improves the state of environmental sustainability as a whole. In some cases it is possible that different stakeholders of the industry use different balance limits. This may cause difference of opinions concerning if the investment is reasonable or not. Sustainability evaluation can be done e.g. with suitable sustainability indices created for this purpose. [10]

Economically, an investment is considered only as a financial expense and this way it is relatively easy to measure. Investment costs usually consist of acquisition costs, operating costs and maintenance costs, which in some cases can be significant. All effects of an investment inside the factory are usually complicated to estimate. A change in the factory process affects material and energy balances inside the factory and hence the operating costs of the plant. An investment can reduce or add the amount of needed person-years and create or reduce the amount of jobs. The reduction of person-years is significant especially in countries where labor force is expensive. Also the working conditions in the factory can alter due to an investment. [10]

For instance alteration in the electricity consumption affects directly the electricity purchasing costs. Also alteration in the raw material market prices has an effect on the running costs of a plant. [10]

An investment is especially important if it can reduce the amount of produced waste and possibly create vendible side-products from a material stream that otherwise would be a waste material stream. An investment can also increase the size of the factory waste material stream. In addition, this often means an increase in waste-management fee. [10]

2.6.3 Economic indices

The economic situation of a company can be evaluated with several different economic indicators. There are metrics created to measure for instance profitability, liquidity, solvency and stability of a company. Profitability can be measured with several different metrics, e.g. Return on Equity (ROE), Return on Assets (ROA), Return on Net Assets (RONA) and Return on Capital Employed (ROCE). Current Ratio and Quick Ratio are commonly used liquidity ratios. [10]

One of the well-known global economic indexes is the Gross Domestic Product (GDP). It describes the country’s ability to produce products and services. It is an index tool for measuring the economic growth. GDP can be defined in nation-level or concerning smaller areas, e.g. cities. It is usually calculated for one fiscal year. One definition of GDP is shown in equation 3.

$$GDP = Private\ consume + Public\ consume + Investments - Import\,. \quad (3)\ [8]$$

GDP does not take housework or voluntary work into account or classify the measured products and services. It also does not take into account the uneven distribution of income in the society. This is why it is questionable to use GDP as a measure of wellbeing of a society. [8]

GDP per capita can be expressed as PPP GDP value, which includes a correction of the purchasing power parity and it is converted into international dollars. The purchasing power of the international dollar is the same as the US dollar has in the United States. Price level and purchasing power vary in different circumstances. PPP GDP value hence enables effective comparison between different countries. [41]

The PPP GDP of different countries is shown on a world map in figure 20 below. The light areas describe a lower PPP GDP value and the dark areas describe higher PPP GDP value. White colour on the map means that there is no data available of these areas. [41]

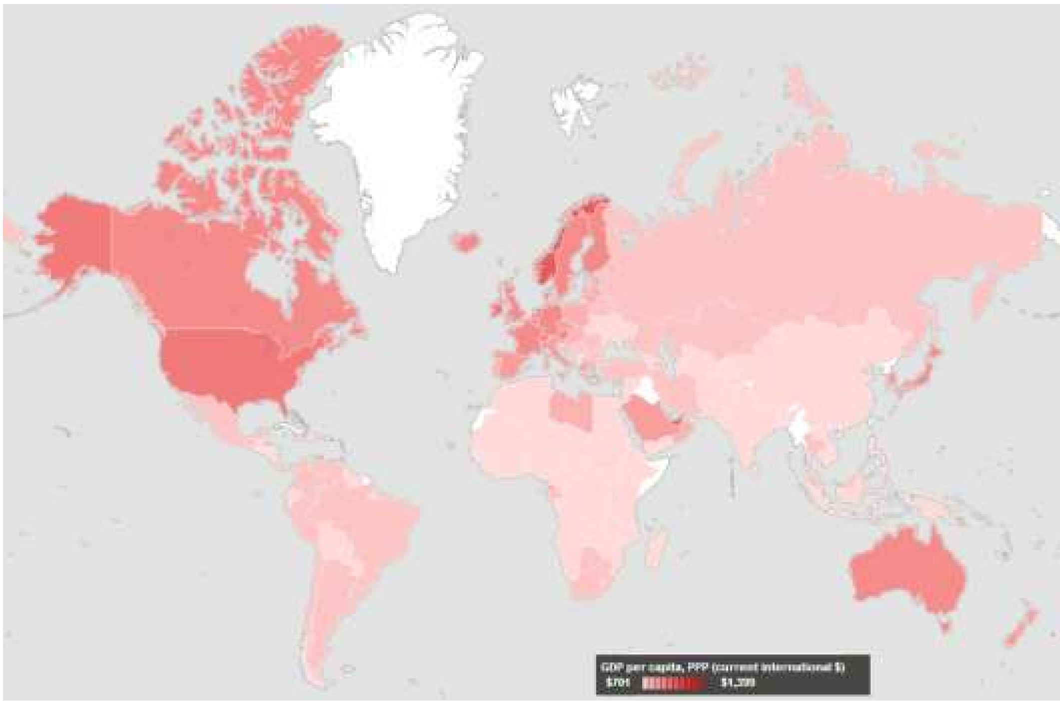

Figure 20. GDP per capita, PPP GDP in the world in 2008-2012. [41]

A popular financial example of Purchasing Power Parity and price level evaluation is the Big Mac Index. It compares internationally the prices of a McDonald's Big Mac hamburger and the currency exchange rates between the United States and the country in question. It was displayed for the first time by The Economist in 1986. [42]

2.7 Social sustainability index

2.7.1 General

Social sustainability issues include the sociological effects that e.g. an industry has on a surrounding society. The key issues of social sustainability index are employment, health and safety, human rights, equality and absence of discrimination, community welfare and distribution of wealth, absence of corruption and bribery, stakeholder involvement and relations with local communities. It is important to notice that for instance responsible business operation and corruption may not always correlate to each other. [2, 10]

Social issues can also be evaluated in micro and macro scale. Micro-level social sustainability issues concentrate on the employees and macro-level social sustainability issues concentrate on the society level. [2]

2.7.2 Wealth creation and risks

Industry creates direct and indirect employment to a significant amount of people in the world. This usually creates wealth in the local society in case the economic gains are distributed evenly in the local society. For example palm oil plantations have gained remarkable benefits for the local households but the distribution is uneven. Migrant workers, also called ‘fly-in, fly-out workers’, are considered to be a sign of unsustainable operations. [2, 43]

In different industries the risk of industrial accidents and also the risk of occupational diseases differ. For instance in mining and minerals industry there is a high accident and fatality risk and dust inhalation on site causes immedicable occupational diseases. [2]

Despite the relatively negative effects on the environment, industrial plants often have a positive effect on livelihoods nearby. Economic benefits and increased wealth cause livelihoods improvement in vicinity of the plant. On the other hand, agriculture and forestry based occupations are forced to step aside to let the industrial plant grow. [2, 43]

2.7.3 Working conditions, labour practices and social investments

Health issues in factory level can be observed by e.g. constant follow-up and reporting of employee's sicknesses, work-related accidents, situations that are nearly accidents, safety procedures and preventative safety procedures. It is important to make these above mentioned operations familiar to employees and prevailing practices inside the company and also demand the company subcontractors to do the same. It is important that the whole supply chain is committed to operate according to sustainable principles. [10]

Training and education matters can be measured by the following factors: with the yearly amount of in-service training and education days per person, the amount of developmental conversations and career guidance, the amount of employees who have signed the code of conduct, and the amount of initiative fee used as a bonus payment for good results. The employee involvement in company business matters and sustaining the employee commitment are also significant issues when training and education matters are measured. [10]

Investments made towards employee's social issues include social investments and social innovations. For instance a new coffee machine in the workplace or supporting and arranging physical exercise and culture events are certain kind of social investments. An electronic debating society in a company website can be considered as social innovation. [10]

Labour practice issues consist mainly of salaries and their national averages, equality, terms and conditions of employment and bonus systems, presence of different age groups, career lengths inside the company, job rotation, child and forced labour, average weekly working hours and amount of overtime work, trade unions and employees taking part in decision making, and the relation of the amounts of part-time, terminable and continuous contracts of employment inside the company. [10]

2.7.4 Corporate Social Responsibility and Corporate Sustainability

Corporate Social Responsibility (CSR) is defined by the World Business Council for Sustainable Development to be “the continuing commitment by business to behave ethically and contribute to economic development while improving the quality of life of the workforce”. Basically it means the co-operation with and support to the local society. This can be e.g. supporting local hospitals and other public services, funding of research, and co-operation with the industry stakeholders, politics and interest groups. [10, 44]

Inspecting different issues on factory level and company corporation level, in order to see if the factor meets the standards, is a part of CSR. Local resistance towards changes in the factory level and handling the resistance is also a CSR issue. [10, 44]

Corporate Sustainability (CS) as a concept is often used as a synonym for CSR. There is a slight difference between these two closely related concepts. CSR defines the ways a company uses its funds and how it affects the surrounding society. CS describes the internal methods of a company to maintain its value and the ability to succeed in the markets. [10, 44]

2.8 Legal aspects

2.8.1 General

One of the main industry stakeholders is the government, which creates frameworks for industrial operations. These frameworks are legislation, taxation, standards for environmental issues and the rights of local communities. Following the legislation has an effect on the 'social licence' of a company to operate. [2]

Legislation is created to e.g. mind the employees' rights, gain income for the public sector, steer the even distribution of gained profit and protect the environment. The basic meaning of environmental legislation is mainly to protect the environment from degradation. Environmental degradation in the long run affects also the other sustainability aspects and can inhibit the use of the area for living or industrial operations. There is a finite amount of land and natural resources available in the world, which means that environmental degradation has to be carefully avoided. [2, 10]

2.8.2 International environmental agreements

A good example of a global environmental legislation contract is the Kyoto Protocol. Kyoto Protocol is a generally accepted international environmental agreement and a part of the United Nations framework convention on climate change. Kyoto Protocol defines binding targets for greenhouse gas emission limits for developed industrial countries. Reduction targets in the Kyoto Protocol countries' greenhouse gas emissions are weighed differently depending on the current industrial status of the country. More developed countries have stricter emission targets than the developing countries because more developed countries' industrially active history is longer and they have continuously created greenhouse gas emissions for even 150 years. [45]

The greenhouse gases measured in Kyoto Protocol are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF_6). Greenhouse gas emissions are measured in the following categories: energy production and use (in e.g. transport, manufacturing and construction), volatile fuel emissions, different industrial processes (e.g. mining, metallurgy, chemical processes, production and consumption of halocarbons and sulphur hexafluoride), use of solvents, agriculture, waste treatment and waste disposal (e.g. landfill, waste waters and waste incineration). [46]

The effectiveness of the Kyoto Protocol on greenhouse gas emission reduction depends greatly on two matters: how well the different parties of the agreement follow the Kyoto Protocol guide book and how reliable the given greenhouse gas emission information is. There are three market-based mechanisms under the Kyoto Protocol that are used as a tool to meet the targets. These three mechanisms are Emissions Trading, The Clean Development Mechanism (CDM) and Joint Implementation (JI). They create the basis of the concept currently known as the 'Carbon Market' or 'Carbon Credit'. These are discussed later in more detail. [35, 44]

2.8.3 Tariffs and certificates

Environmental sustainability development can be advanced by the government e.g. with emissions tariffs. The basic meaning of a tariff is to steer companies to change their habits to more environmentally benign direction. Tariffs (Feed in Tariff FIT or Feed in Premium FIP) are used for instance in energy markets supporting electricity production from renewable energy resources. Feed in Tariff assures a fixed payment to the renewable electricity generator for each energy unit fed into the grid regardless of the current market price. [36]

Renewable electricity production is supported also by Green Certificates. They are certificates the power generator receives for each energy unit produced. Electricity suppliers are bound to buy these certificates up to a certain percentage of the supplied energy. These two above mentioned methods offset the effect of the current market situation on the renewable electricity production and its cost-effectiveness. [36]

Carbon Credit is a good example of an environmental emission tariff. Carbon Credit is a governmental method to steer CO_2 emissions of industrial activities that belong to the Emissions Trading System. It is a purchased permission that allows a company to produce one ton of CO_2. Hence reducing the amount of CO_2 emissions reduces operation costs and makes the industrial operations more profitable. In the European Union the CO_2 emission trading has started in 2005. Until 2012 there has been free allocation of CO_2 emission allowances. In 2013 the emission allowances start to be auctioned. [36]

2.8.4 EU directives

The European Union has created a renewable energy resources directive (2009/28/EC). This directive orders new targets for the consumption of renewable energy resources, e.g. 20 % target for the use of renewable energy resources of final energy consumption and 10 % target for the use of renewable energy resources in transport by the year 2020. However, this directive does not take a stand on where and how the renewable fuels are produced. Hence the sustainability of the whole production chain of the renewable fuel is not taken into account. [10, 36, 43] There is also other legislation for CO_2 emissions, for instance reducing CO_2 emissions in cars (120 g CO_2/km by the year 2015) and the burden sharing agreement for carbon emissions reduction in sectors not included in Emissions Trading System (non-ETS sectors) [36].

The European Union Industrial Emissions Directive (2010/75/EU), IED, has come into operation in 2011. This directive gives boundaries for industrial emissions through environmental permission procedure. IED combines prior environmental directives, such as IPPC directive (the Integrated Pollution Prevention Control directive) concerning industrial emissions, LCP directive (Large Combustion Plant directive), titanium oxide production directive, waste incineration directive and industrial VOC directive (Volatile Organic Compounds directive). IED also elevates BAT methods and BREF documents into a higher repute. [47, 48, 49]

The European Union has made a directive concerning sulphur. The amount of sulphur used in marine fuels is to be reduced from 1.0 % to 0.1 % by the year 2015. This demands large investments for the industry to be able to operate in 2015.The 1.0 % sulphur limit was fulfilled in 2010. [50, 51]

Ships can either change the fuel to diesel oil or liquefied gas with lower sulphur content or install a sulphur washer and continue using heavy fuel oil. The sulphur washer removes the sulphur from the ship flue gas by using different techniques. There is for instance fresh water washer (neutralizes sulphur with lye), seawater washer (alkalinity of the seawater neutralizes the sulphur), hybrid washer (fresh and sea waters techniques combined) and a dry washer (neutralizes sulphur with lime). The sulphur washers remove up to 98 per cent of the total sulphur content. [51, 52]

A ship with a sulphur washer installed is able to use cheaper heavy fuel oil as a fuel so that the flue gas concentration is still acceptable and under emission limits. In case the prices of diesel fuel increases, the sulphur washer cost-effectiveness is emphasized. In the long term the sulphur washer is estimated to be a profitable investment. The more the ship operates, the more profitable the investment becomes and the shorter the repayment period of the investment becomes. [51, 52]

2.8.5 Foreign Direct Investment

Industrial legislation differs in each country and it can be stricter in some countries than in others. Legislation often affects the profitability of a company: costs can be smaller due to more loose legislation. This can also lead to Foreign Direct Investment, FDI, also called the 'China Syndrome'. This means moving the industrial production to countries in which the production costs are low. The purpose of FDI is to lower costs and produce larger profits. The phenomenon can be described as economic integration or globalisation. [53]

Another interesting phenomenon is that after China has started to grow economically, the Sino-African trade has increased significantly. China imports a large portion of its crude oil from Africa. Metals and minerals are also imported from Africa to China. [54]

2.9 Sustainability index summary

2.9.1 General

As it can be seen in the previous chapters, sustainability consists of a large amount of different matters considering nature and environment, social issues or economic issues. These matters mostly are complex and they are connected to each other in multiple ways. This makes the sustainability evaluation relatively challenging. [10]

Due to the complexity of sustainability issues there almost always is something that can be improved. This also means that fully sustainable operations are almost impossible to achieve in real life situations. Easy answers for sustainability problems are rarely available. This creates companies and communities challenges for the future. Long production chains are difficult to control and the origin and sources of raw materials can be hard to find out. [10]

Sustainability has lately become a fashionable term, which is often used to improve the reputation of a company or a product. This can be done based on facts or it also can be used as a misleading marketing strategy, even if there are no true bases for the arguments. This is called greenwashing and it is discussed later in more detail. [55]

2.9.2 Price versus quality

There are certain phenomena that describe the complexity of sustainability issues and production chains very well. A good example of this is the horse meat case in Europe in spring 2013. There was a significant public commotion in Europe about the horse meat findings in ready meal portions. The horse meat was found due to food spot check laboratory inspections. According to the ingredients lists there should not have been horse meat in the product. According to the law, giving false information of a product can be an offence of food supply. [10, 56, 57]

The basic explanation for the episode might be the meat producers' aim to maximize profits in the food production chain at the expense of observing the law and following occupational ethics. The horse meat case affected the Finnish consumer behaviour approximately for one week. [10, 58]

The fundamental reason for the horse meat findings probably lies in the 'money talks' way of thinking in the global markets: food with sufficient quality must be produced as cheaply as possible. In the worst case, this leads to criminal actions, such as the horse meat case. In addition, the production chains often are multiphase and their traceability in most cases is not plain and simple. Hence, all the production chain members are not aware of this type of actions in the production chain. [10]

2.9.3 Greenwashing

Greenwashing is a relatively new term describing a debatable marketing strategy. In greenwashing marketing, a company, product or even a politician is presented in a way that makes it look more environmentally friendly and green than it is in the reality. Greenwashing is in a way misleading the public without directly giving false information. [55]

One method of greenwashing is moving the balance limits of a process in a way that some of the polluting process phases are left outside the inspection area. There a numerous examples about this. For instance hydrogen powered cars can be presented as very green and non-polluting when the fuel making process is left outside of the inspection area. A hydrogen-powered car can possibly improve air quality in metropolises but when the whole production chain is taken under inspection the environmental effects are not significantly smaller for a hydrogen-powered car than a petrol-powered car. [55]

One example of the importance of correctly built balance limits is the Renewable Energy Directive published by European Union. It requires that in the EU area a certain amount of the fuel used must be biofuel. The directive does not define where and how the biofuel should be produced and hence leaves the fuel production out of the inspection area. It is possible that the total sustainability is not improved but even worsened by this directive. [10, 43]

One of the popular biofuel types is palm oil. The effects of palm oil and biofuel production to sustainability are controversial. Plantations cause economic development and provide employment in rural areas. However, social effects are partly negative because of the uneven distribution of income in the area. Environmental effects are negative when forests are converted into palm oil plantations (deforestation). [43]

The above mentioned examples show why it is very important to take the whole production chain of a product into account when observing and analysing its total sustainability. By a thorough investigation, reliable results and realistic conclusions can be attained. Marketing does not always give the right image of the matter, especially when sustainability issues are at stake. [10]

3 Methods and used material

Sustainability index tools created in the Metric project were used to evaluate the collected data. The Metric project sustainability indices and their contents are discussed more detail later in chapter 3. [10]

The case material used in this thesis in cases 1 and 2 is Metric project material. The sustainability indices are calculated with the help of the in the Metric project sustainability index tool. The main purpose of the case examples 1 and 2 is to test if the index tool is useful for sustainability evaluation. The materials used in case examples are from before known cases. This enables more accurate assessment of the sustainability index tool. [10]

The data used in the case examples is collected by following generally accepted sampling principles. Hence it can be considered to be suitable for scientific inspection and reliable results can be achieved. [10]

3.1 Metric project sustainability indices

3.1.1 General

In the Metric project there are three different indices created for the evaluation of sustainability. The three categories are environmental index, social index and economic index. The theory and characteristics of these indices are discussed in general in the previous section. This section concentrates on the three sustainability indices created in the Metric project. [10]

In the Metric project one goal is to create indices to be used on company or single factory level. The major difference between these Metric indices and already existing sustainability indices is that most of the already existing sustainability indices are designed to be used on government level. They are used to e.g. compare different countries and their sustainability performance to each other or measure the development of global sustainability. [10]

A company level sustainability tool can be very useful when building or buying a plant or as a planning aid tool for investment decisions in a plant. Comparison between the sustainability of different plants and companies is also possible. [10]

One important feature in the Metric sustainability indicator tool is that cross-effects can be measured more clearly. Cross-effects are the alteration in other sustainability factors when a modification (e.g. an investment) in a factory process is made. This way the total effects can be highlighted and assessed. [10]

3.1.2 Environmental sustainability index

The Metric project environmental sustainability index is created for estimating the environmental sustainability of a steel plant. The index is calculated with a specific Excel file created for this purpose. The units of the basic data used in calculating the environmental sustainability index are in the International System of Units (SI). They are often announced as an SI unit amount per one ton of product [x/t product]. [10]

The measured numerical emission and other values of a factory are compared to benchmark values, which are the highest and lowest emission values of this field of industry. The lowest emission values are often the values of factories using Best Available Technology (BAT). Highest values are often from old factories with old technology. The benchmark values can be seen in the Excel table. Shown benchmark values and the use of accurate SI unit emission values improve the traceability of the basic data and make the sustainability index results more reliable. [10]

The environmental sustainability sub-indicators are measured on a scale from 5 to -5 where -5 is the best value and 5 is the bottom value. The zero value '0' in the index means that the given result is in the middle of the scale between the benchmark values. The eight different sub-indicators are weighted equally. It is also possible to modify the weights of the sub-indicators case-specifically if necessary. However, in this stage of the construction of the index tool evenly weighed indicators are considered to be the most straightforward evaluation method. [10]

The sub-indicators consist of different components, which are described below in more detail. Also the components of the sub-indicators are equally weighed. There is a separate analysis of heavy metal contents in discharge and emissions. [10]

The environmental sustainability index consists of eight sub-indicators, which are emissions, discharge, solid residues, efficiency, raw materials, transportation and climate change. Environmental legal aspects are discussed separately. The environmental sustainability indicator and its sub-indicators are shown in figure 21 below. [10]

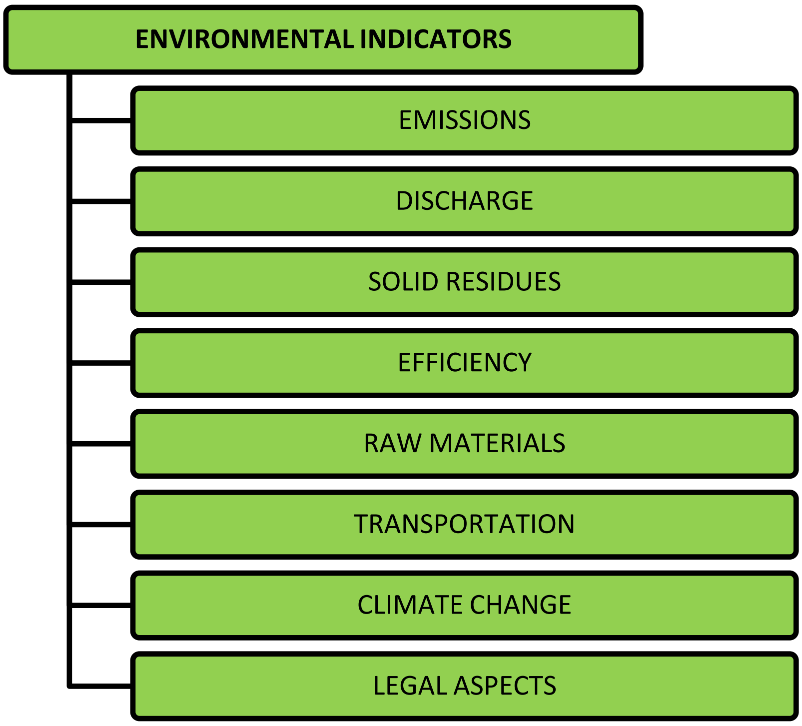

Figure 21. Environmental sustainability indicator and its sub-indicators. [10]

The environmental sustainability evaluation of a test plant is shown in figure 22 below. The final environmental sustainability index of this test plant is -0.8. In the below figure it can be seen that emissions and solid residues indices give quite good results. In raw materials there is a possibility to improve. [10]

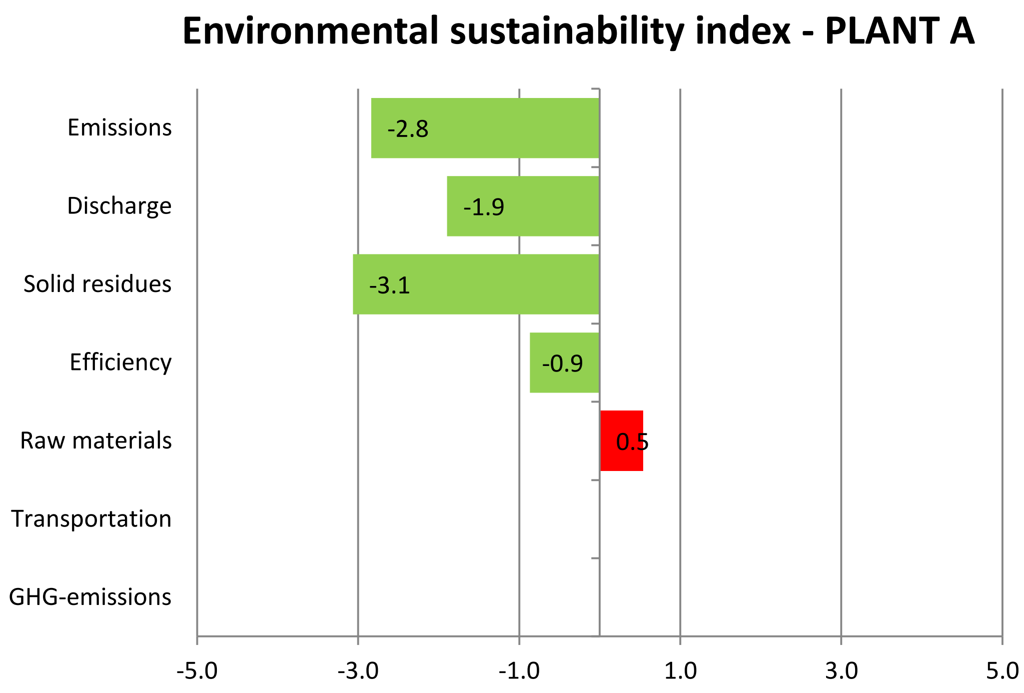

Figure 22. Environmental sustainability index created for a test plant in the Metric project. [10]

Emissions measure CO_2, SO_2, NO_x, dusts and heavy metal stack loads [kg/t product]. Separately measured heavy metals are arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), vanadium (V) and zinc (Zn). [10]

Discharge consists of total effluent flow [m^3/t product], suspended solids, total nitrogen, cyanide and heavy metals (listed above) [g/t product]. Solid residues measure the amount of landfilled waste and the amount of slag [kg/t product], hazardous wastes if any and the utilization rate [%]. [10]

Efficiency consists of energy consumption, material efficiency and water efficiency. Energy consumption measures the amount of energy used, thermal energy produced and the amount of recovered energy [kWh/t product]. Material efficiency measures the amount of non-renewable materials used [kg/t product] and the amount of scrap produced. Water efficiency measures the amount of fresh water consumption [m^3/t product]. [10]

Raw materials indicator is dealt into three categories: production of raw materials, purchased electricity and reducing agents. These are dealt into sub-categories, which are primary energy consumption [MJ/t product], fresh water consumption [m^3/t product] and CO_2 emissions [kg/t product]. [10]

Transportation indicator measures the transportation of raw materials, transportation of additives (e.g. coal/coke for a steel factory) and transportation of products [kg/t product]. All these are measured by the amounts of CO_2, SO_2 and NO_x emissions [kg/t product] and energy consumption [MJ/t product]. [10]

Total greenhouse gas emissions [kg CO_2 equivalent / t product] consist of process emissions, raw materials production emissions, transportation emissions and electricity production emissions summed up. [10]

Environmental-legal aspects are dealt to six sub-categories. They are planning the operations, licence procedures, water resources engineering permission, supervision and legal aspects during the operational phase and ending the operations. These matters are evaluated separately with a series of questions about environmental effects and legislations. [10]

3.1.3 Social sustainability index

The social sustainability index in the Metric project is based on the Worldwide Governance Indicators (WGI) project information (2012). There is detailed social sustainability information separately for each country. This index is also calculated with a specific Excel file created for this purpose. There are several factory level questions to answer. These questions are divided into question sheets depending on the subject. Answering these questions gives a factory its sustainability points and the final result, social sustainability index. [10, 59]

The social sustainability index in the Metric project consist of eight sub-indicators, which are location, supply chain, social innovations, labour practices, training and education, reporting, health and safety and legal-social aspects. The social sustainability indicator and its sub-indicators are shown in figure 23 below. [10]

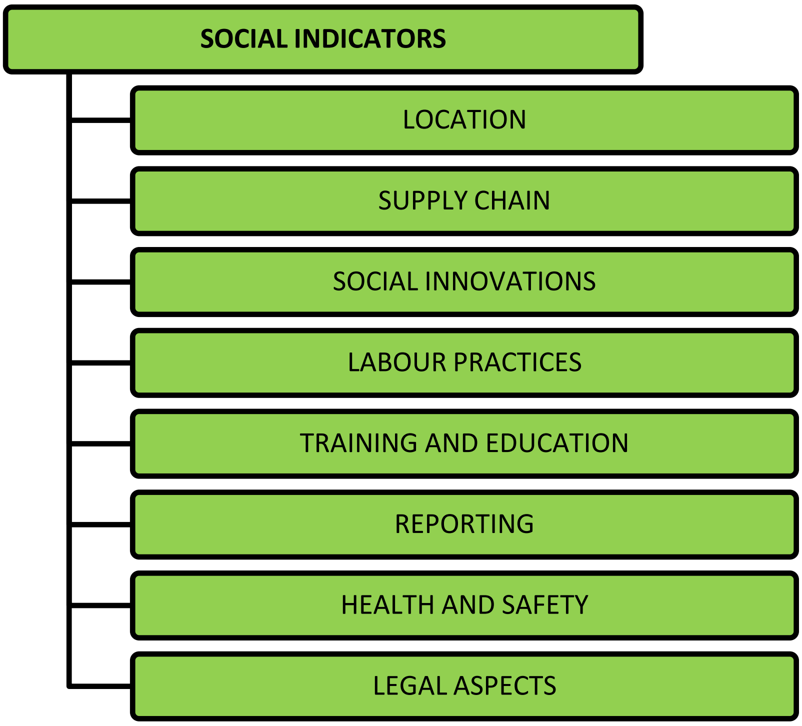

Figure 23. Social sustainability indicator and its sub-indicators. [10]

Sub-indicators and their components are equally weighed. These indicators are also measured on a scale from 5 to -5 where -5 is the best value and 5 is the bottom value. [10]

Social sustainability index and its sub-indices created for a test plant in the Metric project are shown in figure 24 below. In the below figure it can be seen that the factory location is very good and training and education are quite good. There is a possibility for improvement in reporting and legal aspects fields. [10]

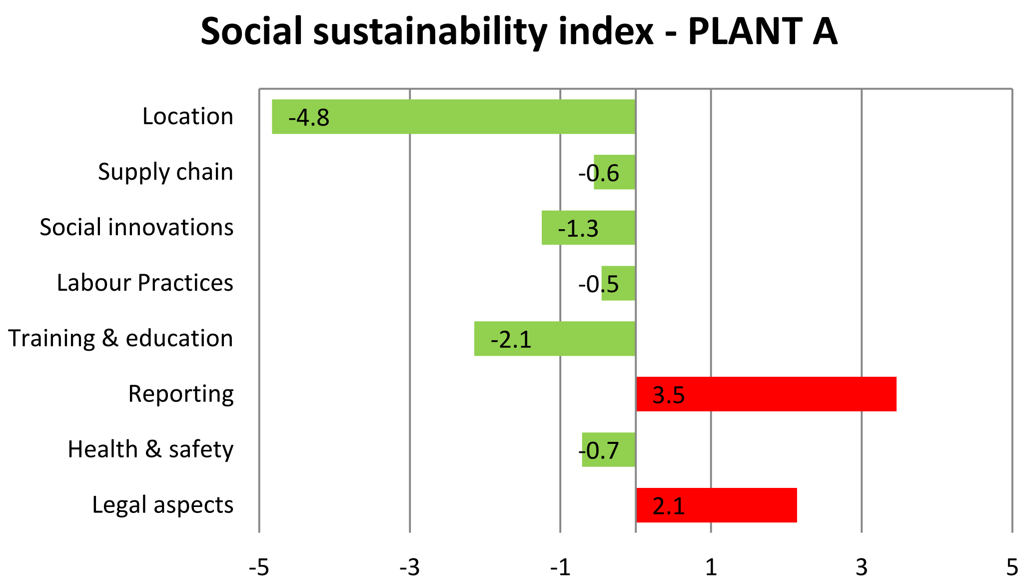

Figure 24. Social sustainability index created for a test plant in the Metric project. [10]

Sub-indices of the social sustainability index consist of a list of questions about the given area. Answers to the questions are mostly 'yes', 'no' or 'not known'. There can also be multiple choice questions with a, b and c alternative answers. Choosing an answer gives the question a numerical value (often -1, 0 or 1). Zero value leaves the matter out of the inspection. These numerical values can be weighed differently if necessary. The final result consists of these given numerical values. [10]

Location indicator consists of voice and accountability, political stability and absence of violence, government effectiveness and regulatory quality, rule of law and control of corruption. [10]

Supply chain indicator consists of a set of questions about the suppliers. The questions are amongst other things related to company's social responsibility, employee's human rights, contract issues, health, safety, education and training. These supply chain indicator questions are listed in the social indicators Excel file in more detail. [10]

Social innovation indicator measures for instance if the social issues are taken into account in the company risk analysis, if there are social investments (e.g. coffee machine, sports and activities) made in the company and if there are new innovations (e.g. principles, practices) on social matters. It measures if the employees are aware of their rights and benefits and if they are able to participate by making initiatives and suggestions. Partnerships and social development are also taken into account. This means e.g. UN Millennium Development Goals, stakeholder engagement and different kinds of social investments. [10]

Labour practices indicator measures standards, salary, monitoring, working time and overtime. Standards part focuses on if there is a code of conduct and if the international working condition standards (e.g. ILO Labour Standard, ISO 26000, GRI and UN Global Compact) are obeyed. Salary focuses on salary levels (national salary averages, all salaries being at least above minimum wages) and that the same salary is paid for same job. It includes all employees having employment contracts and accident insurances, right to have periodic vacations with pay, sick leaves with pay and parental leaves, freedom of association and collective bargaining. [10]

Monitoring indicator consists of career development (job rotation, career length), representation of genders and age groups in different duties, same employee benefits for all and the amount of strikes. Working time and overtime measure the weekly working time and weekly overtime, if overtime work is compulsory and if there are fines or warnings for not working overtime and if the overtime salaries of free compensations are paid correctly. [10]

Training and education indicator focuses on training and education matters as well as skills management and competence development matters. Yearly training and education activities and monitoring of training and education hours per employee are taken into account. [10]

The skills management and competence development indicator consist of code of conduct signed by all employees and their awareness of code of conduct and company values and principles, the ability to give feedback and show ideas, monitoring the sharing of bonuses and fees, monitoring the transfer of explicit and implicit knowledge, monitoring of investments to training and education, training and education of risk management, precautionary measures and workers' rights. [10]

Reporting indicator consists of Corporate Social Responsibility (CSR) and local communities' matters. CSR part focuses on CSR policy, standards and reporting (qualitative and quantitative aspects) and how extensive they are, Global Reporting

Initiative (GRI) activities, commitment to social responsibility (reporting and continuous improvement), risks communication plan and proactive change communication policy. [10]

Local communities indicator measures the contribution of a company on well-being of the local community by offering direct and indirect employment, paying taxes, community involvement (charity donations and events), community consultation and support reporting policies. Occupational health and safety indicator focuses on safety principles, practices, training, audits and monitoring, preventive safety actions such as education and training in first aid and serious diseases, injury rates and monitoring, employee insurances, occupational diseases, fatality rates and monitoring, absenteeism and safety in supply chain. [10]

The legal-social indicator consist of six categories, which are employment contract and labour unions, employment and salary, working hours and leaves, employees, young employees and liability. Employment contract and labour unions part concentrates on if employees have a right to organize, build a labour union and strike, if there is a collective agreement of work matters between labour unions and the employer and if it defines minimum contract terms. [10]

Employment and salary indicator is about complying minimum wage and minimum period of notice, severance payment and probationary period. In working hours and leaves part there are matters such as maximum working hours and overtime payment, right to paid annual leave, the length of the working week and weekly rest and the possibility of a study leave. [10]

Employees indicator measures occupational health service, working safety monitoring, discrimination, protection of personal data and possibility for co-determination. Young employees part focuses on underage employees. Liability part consists of liability responsibilities of a company and its subcontractors. [10]

3.1.4 Economic sustainability index

In the Metric project the economic sustainability index construction is in early stage. The discussion on the economic indicator and its contents and their importance has not been completed during the writing of this Master's thesis. Hence, in the case examples in this thesis the economic evaluation will be done based on the financial statistics of the factory, the investment cost and their relations. The further construction of the economic indicator is suggested to be a part of further study. [10]

The newest planned sub-indicators of the economic indicator are key financial statistics, investments, raw materials and energy, risks, supply chain, social aspects etc., cross effects, costs based on legislation and legal aspects. The legal aspects indicator is created by researchers in University of Helsinki. The economic sustainability index sub-indicators are shown in figure 25 below. [10]

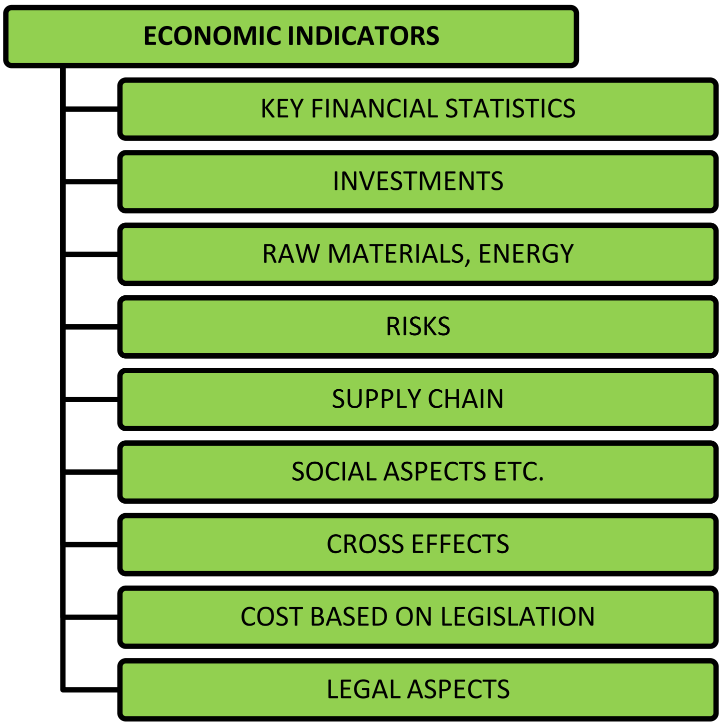

Figure 25. Economic sustainability indicator and its sub-indicators. [10]

The legal aspects indicator consists of five categories, which are retirement pension, disability pension, health insurance, accident insurance and taxation. The retirement pension measures if the employer arranges the retirement pension insurance for the employee, if it is arranged better than the statutory obligation and if there are a minimum and maximum retirement pension age prescribed in the law. [10]

Disability pension indicator measures if arranging the disability pension insurance for the employee is the employer's duty and if it is arranged better than the statutory obligation. Health insurance indicator measures respectively the above mentioned matters but considering health insurance. [10]

Taxation indicator measures if the economic result of the company is taxed in the country in question, if the company is paying real estate tax and municipal tax and if there are tax reliefs considering the operations in question. It also measures if the company can be condemned as a juristic person to be responsible for an economic ('white-collar') crime. [10]

The questions in the legal aspects sub-indicators are answered either 'yes' or 'no'. The numerical values from these two answers are 1 for 'yes' and 0 for 'no'. They can also be concerned so that the answer 'no' gives a negative value, -1. The given numerical result is weighed based on the importance of the subject (some of the subjects are weighed worth a double). The relative importance of the sub-indicators is evaluated by the researchers of University of Helsinki. The sum of the weighed values gives the final index value result. [10]

The economic sustainability index tool construction in the Metric project is in early stage in other areas than the legal aspects sub-indicator. Hence, in the case examples in this thesis the economic evaluation will be done briefly based on the financial statistics of the factory and the investment cost and their relations. [10]

4 Research methodology and results

The research part of this thesis consists of two case examples and their results. The cases are analysed by using the sustainability index tools created in the Metric project. Case examples are existing and before known examples from the industry. Both cases concern an environmental investment decision in a factory. Case 1 is about relatively high concentrations of small particles in the factory emissions and installation of particle emission collector equipment. The case 2 is about high concentrations of COD in factory discharge and installation of tertiary treatment in pulp mill discharge cleaning unit. [10]

The case examples are evaluated with environmental sustainability index tool created in the Metric project. The evaluation is done before and after installing the investment. The change in the sustainability state is observed with the help of given index values. [10]

The social sustainability analysis is made in case 1. Unfortunately, in case 2 the social sustainability information is not available and hence the social sustainability of case 2 is not analysed in this thesis. [10]

The construction of economic sustainability index tool is in early stage in the Metric project. Hence, there is a brief economic situation analysis in both case examples. Return on Investment (ROI) cannot be used, because it includes gain from investment. The investments in cases 1 and 2 do not have a repayment period. Hence, there is no gain from investment. In case 1 the economic analysis consists of company average annual profit, investment costs and recycled material income. In case 2 the economic analysis of the discharge cleaning unit and tertiary treatment is done based on investment costs and comparison between discharge cleaning costs before and after the investment. [10]

4.1 Case 1: Particle emission collector

4.1.1 General

This case example deals with high concentrations of small particles measured in vicinity of a factory area. Due to these high concentrations of small particles, the local authorities demanded the company to block large open areas in the roof of the factory building and also to purchase and install particle emission collector equipment. The particle emission collector equipment has not been yet taken into use when writing this thesis. Hence, the information concerning the situation after the investment is modelled and calculated estimations. [10]

Before blocking the roof open areas and installing the particle emission collector, small particle concentration inside the factory in the working area was 1 – 3 mg/m^3, which is much less than the 10 mg/m^3 upper limit of HTP$_{8h}$-value. The annual small particle emissions of the factory were approximately 500 tons. After blocking the large open areas in the factory roof, the small particle concentration inside the factory in the working area is less than 5.0 mg/m^3. The small particle emissions of the factory are estimated to be less than 5.0 mg/Nm^3 (milligrams per cubic meter at normal air pressure) after the investment. Due to the investment, a decrease is observed in small particle concentrations in vicinity of the factory, and an increase is observed in the particle concentrations in the factory working area. [10, 19]

The demanded particle emission collector equipment capacity is approximately 2.0 million cubic meters of air per hour [m^3/h]. This means 550 cubic meters of air per second [m^3/s]. The electric power of the motors is 5100 kW total. The electricity consumption is 30 GWh/a. [10]

The operating costs of the factory increase 2.1 M€/a. They consist of electricity consumption costs 1.9 M€/a, pressurized air 0.1 M€/a, and maintenance costs 0.1 M€/a. Recyclable material is collected approximately 1500 tons per year. This brings cost savings and profit 0.25 M€/a total. [10]

Increase in factory electricity consumption increases the CO_2 emissions of electricity production by 6000 tons per year (calculations are based on the average emissions of energy production in Finland). [10]

4.1.2 Positive and negative effects

The positive effects of the particle emission collector are that the small particle concentration decreased approximately by 2 - 4 µg/Nm^3 in the vicinity of the factory. Hence, the living conditions and convenience of the nearby residents is improved and possibly also new residences can be planned and built even closer to the factory than before. Recyclable material can be collected more than before, which creates income to the company. [10]

The downsides of the investment are that the electricity consumption and global CO_2 emissions increase due to the investment. Installation of the particle emission collector increased the amount of small particles in the factory working areas, which worsened the working conditions and industrial health. The investment is relatively expensive, approximately 30 M€, and it has no repayment period. Annual costs of the investment are 1 850 000 €/a, which is equal to approximately 30 person-years. The cost increase reduces the possibilities of the company for improving their operations by development investments. [10]

4.1.3 The index tool analysis

The environmental sustainability index for case 1 is calculated considering the whole factory. Because of this large scale inspection, the alteration in the results is relatively small. However, it must be taken into consideration that in larger scale even a small change is significant. The results of the index tool analysis are shown in figures 26 and 27 below. [10]

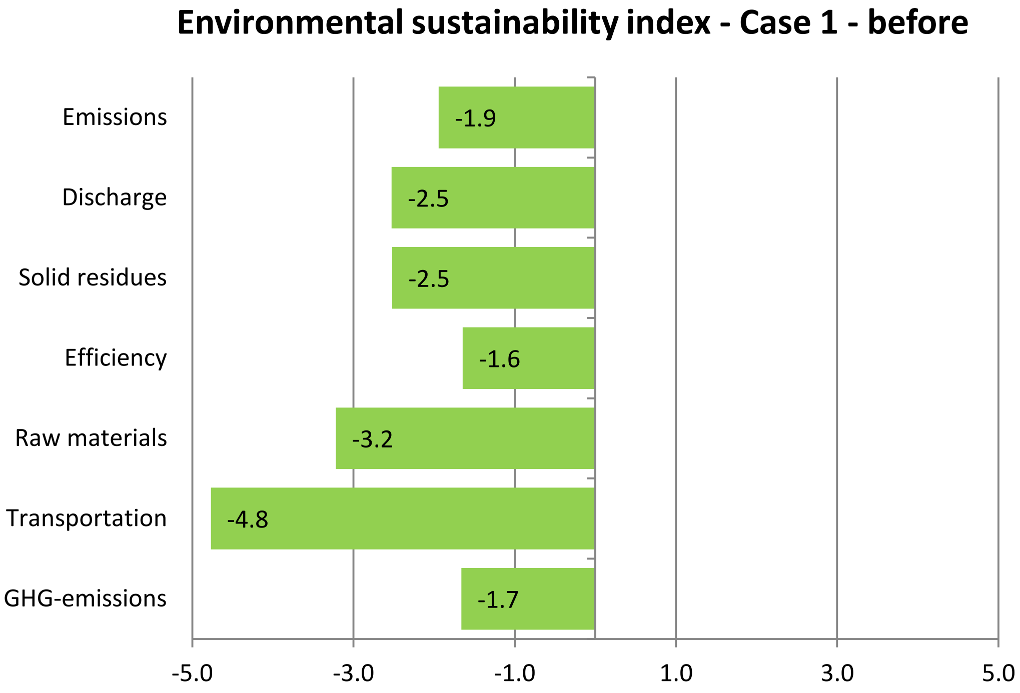

Figure 26. Case 1 environmental sustainability index, measured before the investment. [10]

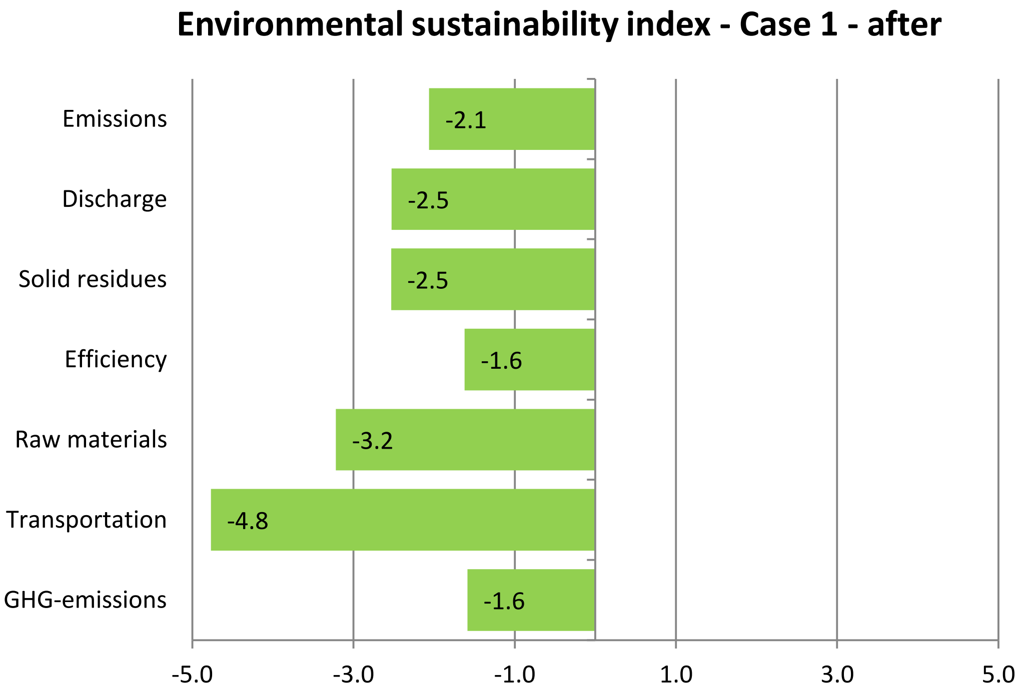

Figure 27. Case 1 environmental sustainability index, evaluation of the situation after the investment. [10]

In the above figures it can be seen that the investment lowers emissions (small particles and dusts) but also there is an increase in the creation of greenhouse gases due to the increase in electricity consumption. The total environmental sustainability of the factory is -2.6 in both cases. This means that the investment does not significantly affect the total environmental sustainability of the factory. The changes of the environmental sustainability state of the discharge cleaning unit are shown in figure 28 below. [10]

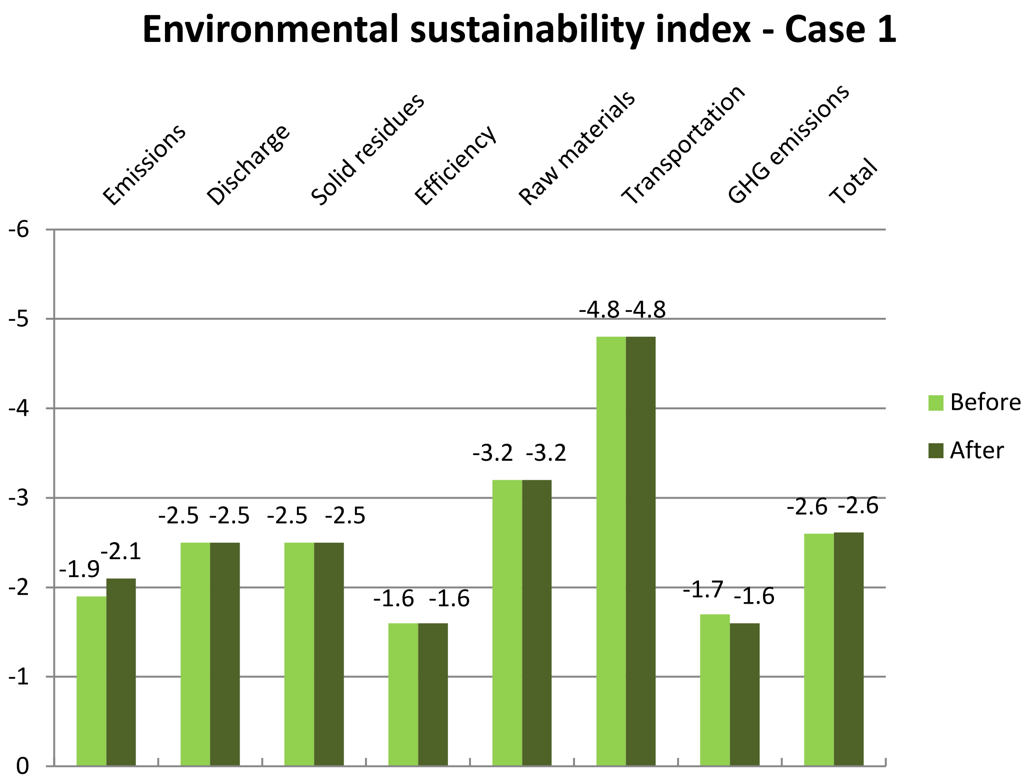

Figure 28. Case 1 environmental sustainability index results and comparison before and after the investment. [10]

The social sustainability index tool considering this case example was filled in by a co-operation company, because the index tool contains such information that has to be collected inside the company in order to get true results. The results of the social sustainability index describe the situation before the investment. The results of the social sustainability index of case 1 are shown in figure 29 below. [10]

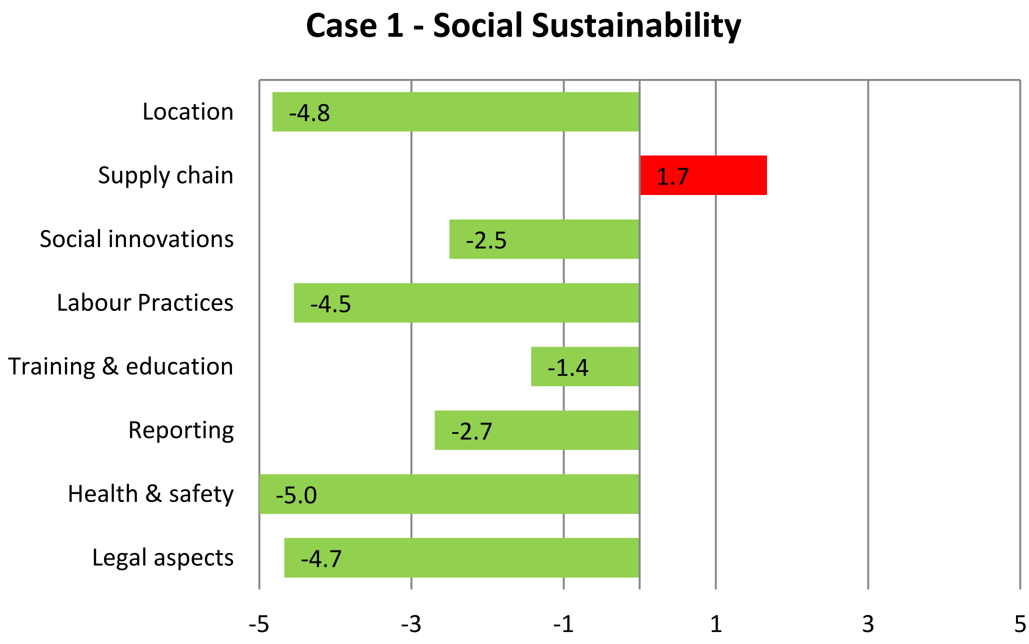

Figure 29. Case 1 social sustainability index results. [10]

From the above figure it can be seen that the company's social sustainability is in a very good or excellent shape in areas of location, labour practices, health and safety and legal aspects. Social sustainability of social innovations, training and education and reporting are in a good shape. The total social sustainability index value is -3.0. [10]

In supply chain sustainability there seems to be a possibility to improve. However, it must be considered that the index tool questions related to supply chain do not take into account the amount of suppliers. When the number of suppliers is several hundreds or even thousands, it is very challenging to be well informed of all suppliers' social issues. [10]

There are estimated two significant changes of the social issues due to the investment. Firstly, increase in the amount of small particles inside the factory working area and hence deterioration of working conditions. Secondly, there is a possibility of cost cuts concerning social investments, such as supporting employee free time activities, sports and clubs. [10]

Both of the above mentioned matters are significant issues and also hard to show with the index tool. At the moment, the index tool gives the same values for social sustainability before and after the investment. Hence, the quality deterioration cannot be seen in the index values. The main reason for this is that the tool takes sustainability matters into account in yes/no/not known level. This is mentioned in suggestions for further study. [10]

The brief economic analysis of case 1 is shown in figure 30 below. The analysis shows the company average annual profit (years 2009 – 2012, there has been operating loss and hence profit value is negative), the investment cost (30 M€), the annual investment maintenance cost (2.1 M€/a) and the collected recyclable material income (0.25 M€). The investment cost is approximately 30 % of the company average annual profit. [10]

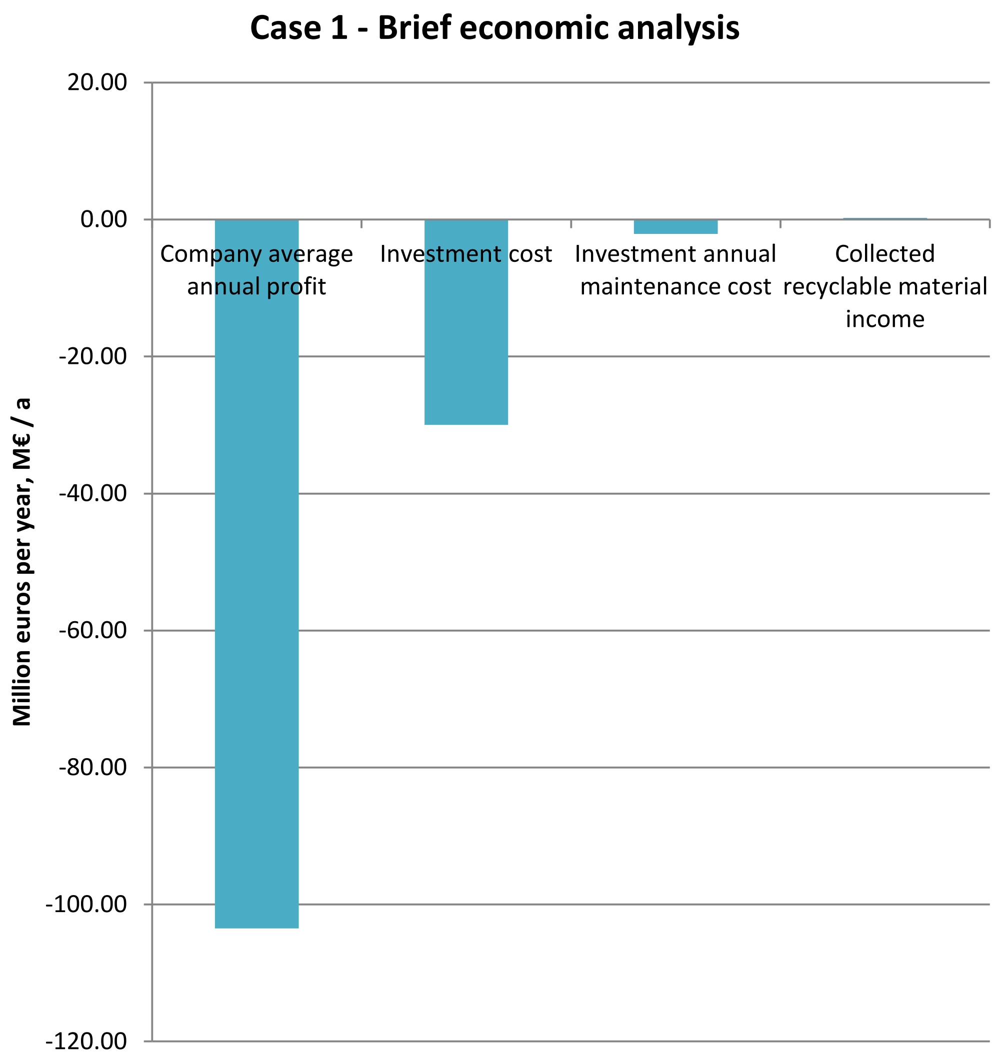

Figure 30. Case 1 brief economic analysis. [10]

4.1.4 Conclusions

In conclusion, the particle emission collector investment has wide-ranging effects to the related sustainability matters. All these detected effects must be evaluated carefully to see if the total sustainability of the factory operations was improved or not due to this investment. [10]

Based on the environmental sustainability index, the total environmental sustainability index gives the same total value before and after the investment. Hence, the environmental sustainability state of the factory does not change due to the investment. It must be taken into consideration that the environmental analysis is calculated for the whole factory. This is a relatively large scale and this is the main reason that only small changes can be seen in the environmental index results. [10]

The social index values do not change due to the investment. However, there are significant changes estimated in social issues in the factory level, but they are changes in quality and unfortunately are not seen in the social sustainability index results. Hence, quality of social sustainability deteriorates to some extent, although it cannot be seen in the index values. Quality factor should be added to the social sustainability index tool in order to see sustainability quality changes. It is also possible that continuous measuring would show the changes in social issues. [10]

In the brief economic analysis the average annual profit (in this case operating loss) of the company is compared to the investment cost and investment maintenance costs. The investment cost is approximately 30 % of the average operating loss which is a significant amount. [10]

4.2 Case 2: Waste water cleaning unit

4.2.1 General

The case 2 is about high concentrations of Chemical Oxygen Demand (COD) organic compounds in chemical pulp mill waste water. The water is bled into the surrounding waterways. Due to these high concentrations of COD, the local authorities demanded the factory to purchase and install tertiary water treatment part in order to reduce the amount of COD. The mill's water treatment system including primary, secondary and tertiary treatments, are shown in figure 31 below. [10]

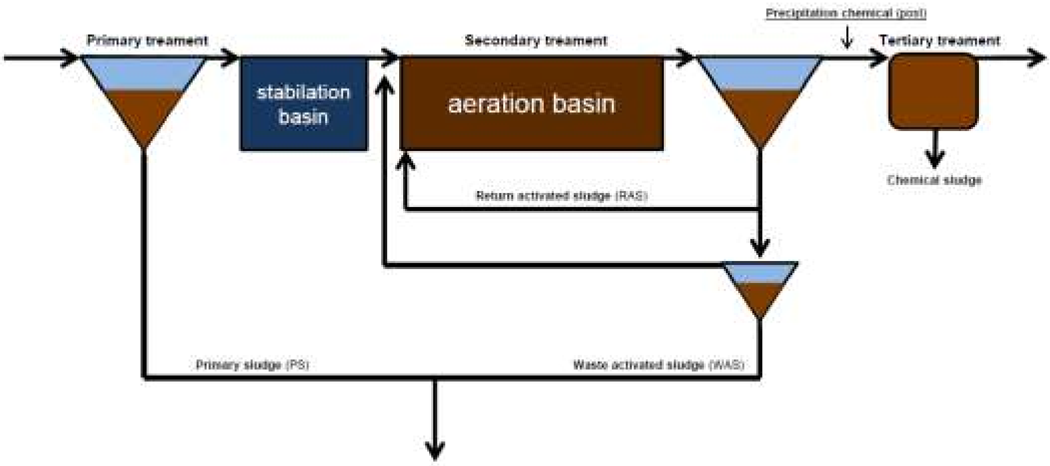

Figure 31. Water treatment equipment of the case 2 factory. [10]

The purpose of this case example is to evaluate the situation of the waste water treatment before and after the investment. The energy and material inputs and outputs change due to the investment. The change in the sustainability of the discharge cleaning unit is assessed by using the Metric project sustainability index tool. In case 2 the focus will be on the environmental index tool. There is also a short cost analysis of the investment. Social aspects in case 2 are not taken under observation because reliable information of the social issues considering this case is no longer available. [10]

4.2.2 Positive and negative effects

The tertiary water treatment will reduce the amount of COD in the mill waste waters. More thorough removal of COD will increase the demand of water treatment chemicals. [10]

The tertiary water treatment requires an additional water cleaning chemical, which is aluminium sulphate. This will create discharge sludge containing aluminium. Also the amount of sludge created in the process increases due to the investment. Before the tertiary water treatment investment the discharge sludge was disposed in bark boiler or recovery boiler inside the factory area. Sludge that contains aluminium cannot be disposed by incineration. Hence, the sludge containing aluminium must be put to landfill. The amount of landfilled waste increases significantly due to the investment. [10]

4.2.3 The index tool analysis

The environmental sustainability index analysis is shown in figures 32 and 33 below. These figures describe the situation of the discharge cleaning unit before and after the investment. Emissions and efficiency are left outside the inspection area. [10]

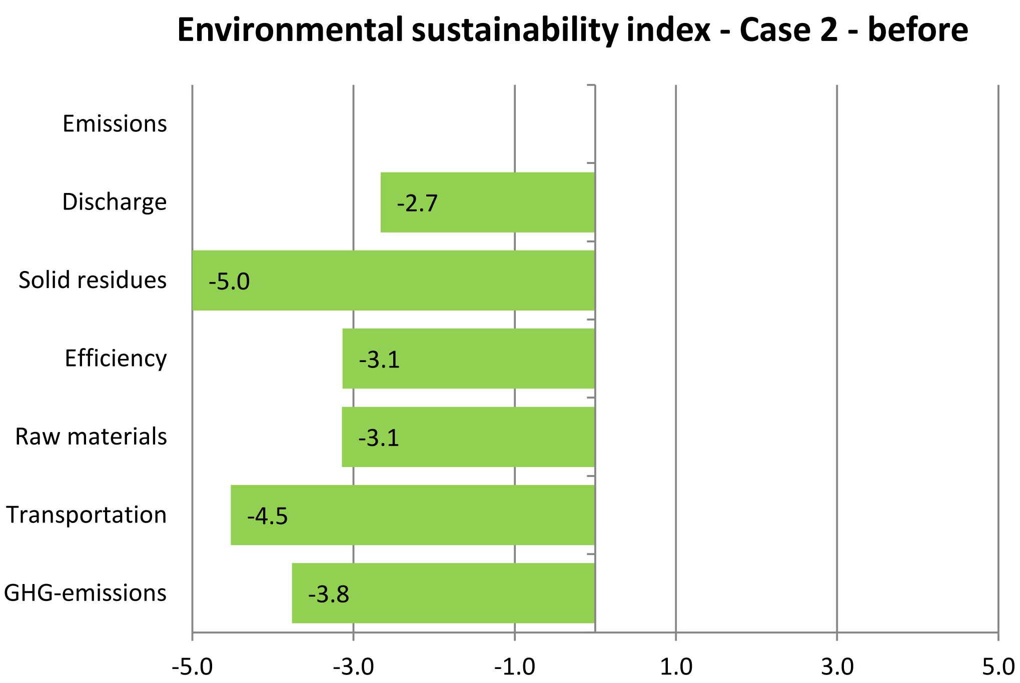

Figure 32. Case 2 environmental sustainability index, evaluation of the situation before the investment. [10]

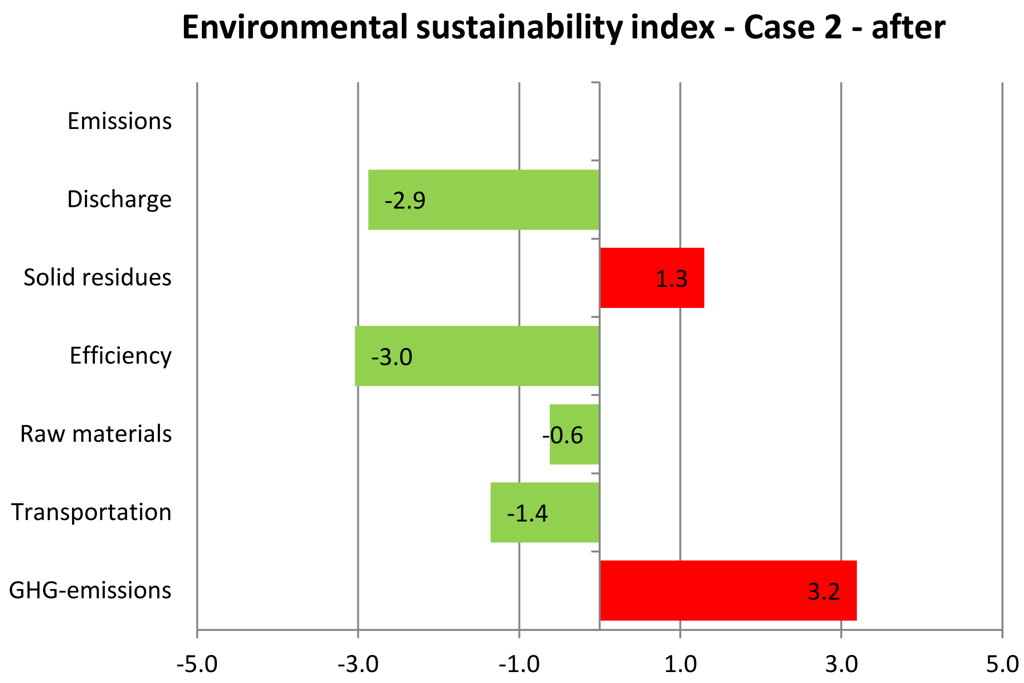

Figure 33. Case 2 environmental sustainability index, evaluation of the situation after the investment. [10]

The discharge cleaning unit sustainability state and its alteration due to the investment can be seen by comparing these pictures. Discharge index value before the investment is -2.7 and after the investment it is -2.9. There is a small improvement in, total 0.2 units. The greatest changes are in solid residues and GHG emissions. [10]

Solid residues measure the amount of waste put to landfill. Before the investment, the sludge was disposed inside the pulp mill. Hence, there was no landfilled waste created in the discharge cleaning unit. After the investment the sludge contains aluminium and it must be put to landfill. This increase in landfilled waste amount can be seen in the index results: The solid residue value before investment is -5.0 (no landfilled waste) and after the investment it is 1.3. There is 6.3 units deterioration in the solid residue index value, which is a significant change. [10]

Efficiency before the investment is 3.1 and after the investment it is 3.0. There is a small 0.1 unit deterioration in efficiency due to the increased electricity consumption. Raw materials index value before the investment is -3.1 and after the investment it is -0.6. There is 2.5 units deterioration in the raw materials index value due to the increased need of water cleaning chemicals. [10]

The transportation index value before the investment is -4.5 and after the investment it is -1.4, total deterioration being 3.1 units. The change in transportation sustainability is caused by increased need of transportation of water cleaning chemicals. [10]

GHG emissions increase is mainly caused by the increased transportation of chemicals. GHG emissions index value before the investment was -3.8 and after the investment it was 3.2. This is a significant change, total 7.0 index units. [10]

The total environmental sustainability index value before the investment is -3.2 and after the investment it is -0.6. This means that the total environmental sustainability of the discharge cleaning unit deteriorates 2.6 units due to the investment. The above mentioned changes of the environmental sustainability state of the discharge cleaning unit are shown in figure 34 below. [10]

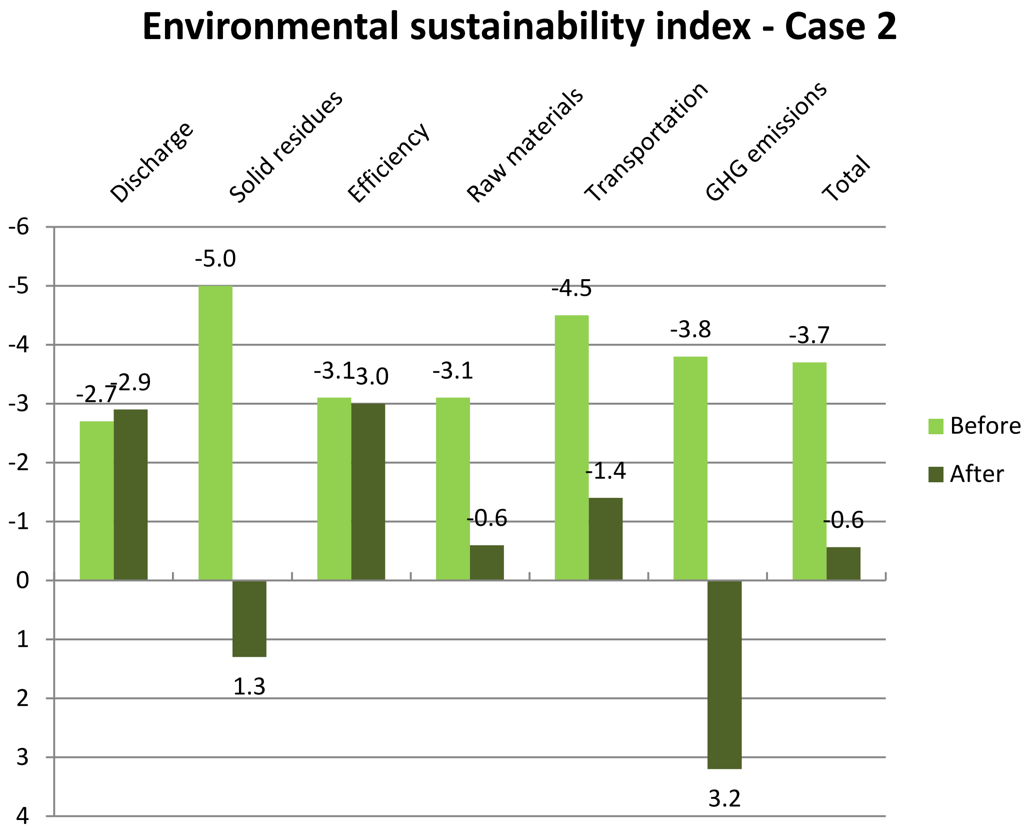

Figure 34. Case 2 environmental sustainability index results and comparison before and after the investment. [10]

The economic situation of the factory discharge cleaning unit also changes due to the investment. The discharge cleaning costs are dealt into two categories: variable costs and fixed costs. They are shown in figure 35 below. [10]

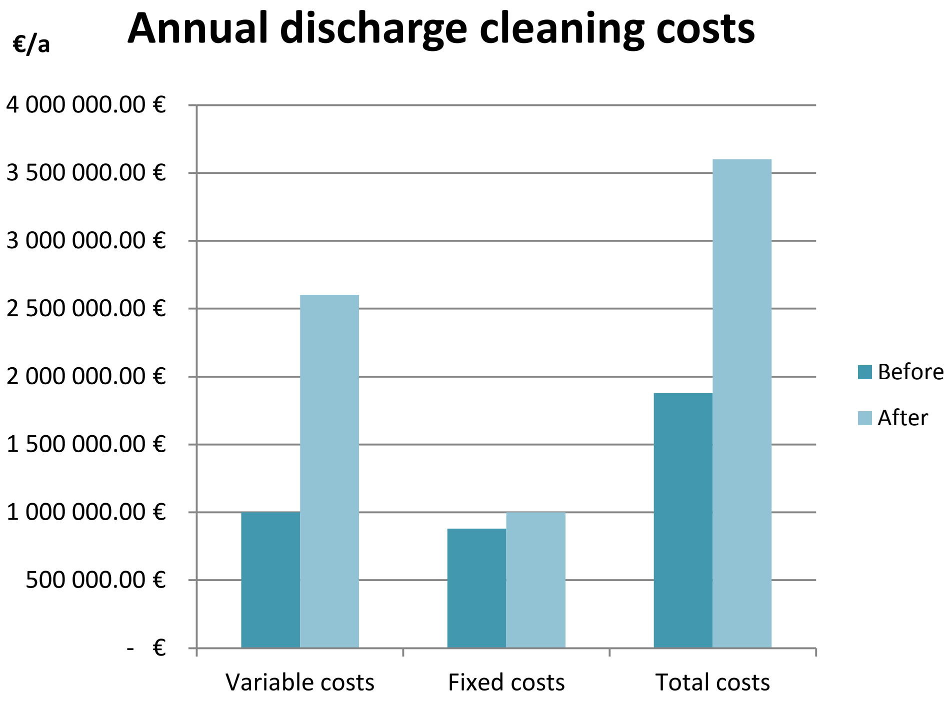

Figure 35. Case 2 discharge cleaning costs divided into variable costs and fixed costs and total costs, before and after the investment. [10]

According to the above figure, the discharge cleaning variable costs increase significantly due to the investment. Variable costs in this case consist of primary and biological water cleaning chemical and material costs, sludge treatment costs, maintenance costs and electricity costs. Tertiary discharge cleaning and its sludge treatment costs create the difference between the situation before and the situation after the investment. [10]

Small increase can also be seen in discharge cleaning fixed costs. These costs are estimated based on the total investment costs of the discharge cleaning unit, which are divided by the expected life of the cleaning unit. The investment costs of a discharge cleaning unit with a tertiary treatment are larger than the discharge cleaning unit without a tertiary treatment. Total costs sum up variable and fixed costs before and after the investment. [10]

4.2.4 Conclusions

The 2.6 unit reduction in environmental sustainability index value describes that the total sustainability of the discharge cleaning unit deteriorates due to the investment. Increased need of transportation of water treatment chemicals increases the greenhouse gas emissions created by transportation. Creation of sludge containing aluminium increases significantly the amount of landfilled waste. [10]

The economic analysis shows, that variable and fixed costs increase due to the investment. Variable costs increase significantly and fixed costs there is a relatively small increase. The relation between total costs after the investment and total costs before the investment is approximately 1.9, which means that the costs increase significantly due to the investment. [10]

As a conclusion, the investment reduces total environmental sustainability of the chemical pulp mill discharge cleaning. There is a small improvement in the quality of discharge water fed into the surrounding waterways. The investment increases the discharge cleaning costs of the mill, which have to be covered by savings on other functional areas. The investment does not create additional economic income. [10]

5 Conclusions

The given results of cases 1 and 2 show that there are changes in the environmental sustainability areas due to the made investments. In case example 1 the inspection area is the whole factory. This means that the inspection scale is relatively large and even a small alteration in the index values is significant. The environmental sustainability index results slightly alter between sub-indicators (reduced direct emissions and increased GHG emissions). The total environmental sustainability index value in case 1 is the same before and after the investment. From these given results it can be seen that the investment in case 1 does not improve or worsen the state of environmental sustainability of the factory. [10]

In case 2 the inspection area is the discharge cleaning system before and after installing the tertiary treatment unit. Due to the smaller scale of inspection area, the case 2 environmental index results show significant changes. Total environmental sustainability index value change is 2.6 units deterioration, caused mainly by the increased need of chemicals and their transportation, and formation of landfilled sludge. Based on these values, it can be written that the total environmental sustainability of the discharge cleaning unit actually deteriorates due to the tertiary treatment investment. [10]

The social sustainability index tool was used only in case 1. In case 2 there was lack of information of social issues. In case 1, there was a problem with quality factors in the social sustainability index tool. The co-operation company has observed and estimated changes in their factory level social issues, such as deterioration of working conditions inside the factory working area and reduced possibilities to make research and development investments and social investments. However, these before mentioned quality issues cannot yet be presented with the social sustainability index tool. Because of this, the social sustainability index tool shows no changes in social sustainability, even though there is observable deterioration in social issues due to the investment. [10]

In both case examples there is a short economic analysis concerning the investments. Both investments are environmental investments, which in this case means that they have no repayment period. Both of the investments increase annual costs (e.g. raw materials and maintenance) in addition to the investment cost. Based on these brief economic analyses, it can be written that case 1 and 2 investments are not economically viable. [10]

In both case examples the environmental indicator shows similar effect: there is an investment made, which is supposed to improve a specific environmental sustainability matter, and at the same time one or several other sustainability matters deteriorate. In case 1 there is no change in the total environmental sustainability and in case 2 the total sustainability deteriorates. In case 1 the co-operation company has observed quality deterioration in their social sustainability due to the investment, even though it cannot be seen in the measured social sustainability index results. There is no repayment period for these two investments and they are not economically viable. Thus, neither of these two investments is justifiable based on the environmental or social sustainability index tool or brief economic analysis results. Based on these results, it can be written that the total sustainability of an environmental investment should always be analysed with high accuracy in order to make decisions that truly improve the environmental sustainability state. [10]

As a summary, the use of sustainability indicators as an evaluation tool seems to be an effective way for companies' self-evaluation of made investments. Most likely, it can also be used for comparison between different sites inside a company. In order to get truly comparable results the responses must be truthful and interpret different sustainability related matters similarly in all cases. In this thesis the sub-indicators are weighed equally, which naturally affects the results. It is also possible to weigh a sub-indicator more heavily in case this is truly reasonable. [10]

6 Suggestions for further study

In this thesis, case examples 1 and 2 were analysed with the sustainability index tools created in the Metric-project. Both case examples are before known. Hence, the sustainability index tool itself can be analysed as thoroughly as possible. However, both case examples are environmental investments. Next step of using the sustainability index tool could be through another investment type – e.g. special products investment or an investment that improves cost efficiency. [10]

The environmental sustainability index tool should be modified to be more flexible e.g. with different used raw materials and waste streams, and amounts of different fractions. This way it would be easier to use the tool for different type of industrial applications. [10]

In the environmental sustainability index tool the raw materials are measured by used amounts of raw materials or emissions [kg/t product]. However, different raw materials create different environmental load. This probably should be taken into account by using for example the Ecological Rucksack as base information when giving weights to different raw materials usage in the index tool. In the environmental sustainability tool there could be collected information of Ecological Rucksack values of different raw materials. [10]

Finding the right reference values for the environmental index has proven to be relatively hard and time-consuming task. Minimum reference values are often found in the EU BREF documents. Maximum reference values are in most cases emission values of an old mill without recent technology and these values are not always easy to find. In case examples 1 and 2 the main idea was to evaluate the alteration in index results, which can be done with substantially correct references. Precise reference values must be found in order to compare different sites to each other. Also collecting a list of references for different industrial processes could be possible. Enough time must be reserved for finding the reference values. [10]

In case 1, filling in the social sustainability index tool was considered to be a relatively heavy task in the co-operation company. The questions of the social sustainability index tool are mostly answered ‘yes’, ‘no’ or ‘not known’, but there is a great amount of questions included. Hence, sufficient amount of time must be reserved for filling in the index tool in order to get true results. Also it should be made easier and clearer to leave out some questions in the social sustainability index tool by weighing them with the value zero (0). [10]

In the social sustainability index tool, most questions are answered 'yes', 'no' or 'not known', which works quite well in most cases. However, in case example 1 the co-operation company has observed that there is deterioration in working conditions inside the factory working area and also estimated possible cost cuts in research and development investments and social investments. These are such matters that cannot be seen in the index results, because the whole activity does not stop but reduces or deteriorates. Hence, in the index tool there should be a possibility to add quality factor when this is needed. The quality factor could for example describe a sub-indicator state in scale from 1 to 5 or from 1 to 10. Hence, the quality improvements or deteriorations could also be taken into account when calculating the index. Also continuous annual measuring could be a possible method for detecting alteration in social sustainability issues. [10]

One interesting question about the social sustainability index tool is that is it possible to see differences between different countries in the index results. The index tool could help the evaluation of the social issues when a company is planning to move their production e.g. into the developing countries. First, some testing and possible modifications should be made with the social sustainability index tool. [10]

The construction of economic sustainability index tool is yet in early stage. There is a draft of matters that should be included in the economic index, but these are still being discussed inside the project team, because there was considered to be too many listed issues. The construction of the economic index tool should be continued. [10]

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